CONTRACT NO. 92-330
FINAL REPORT
DECEMBER 1993

Aircraft Measurements of Ozone and Meteorological Variables over the Sacramento Valley

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

Aircraft Measurements of Ozone and Meteorological Variables over the Sacramento Valley

Final Report

Contract No. 92-330

Prepared for:

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December 1993

ACKNOWLEDGEMENTS:
Mr. S. Malkin and Mr. M. Pyle, students, assisted in the processing and reduction of the data collected. Mr. Alan Dixon was the pilot for two of the flights. Their valued assistance is gratefully acknowledged. This work was supported in part by the Experiment station of the University Division of Agriculture and Natural Resources.

DISCLAIMER:

ABSTRACT:

The primary objective of this project was to use an instrumented aircraft to measure *in situ* vertical distributions of ozone concentrations. These data are to be used to verify profiles of ozone measured by a ground based remote sensing system. Differential absorption LIDAR (DIAL) systems can, under certain conditions, be used to measure trace gas concentrations as a function of distance from the instrument up to several kilometers. The design concept is to emit pulses electromagnetic radiation at two closely spaced frequencies, one in an absorption band of the gas to be measured and one just outside of the band. The difference in the energy backscattered to the instrument at the two wavelengths can be used to estimate the amount of absorbing gas between the source and the back-scattering aerosol particles. The Wave Propagation Laboratory (WPL) of the National Oceanographic and Atmospheric Administration (NOAA) has developed such an instrument for measuring ozone. The DIAL system was pointed upward and capable of measuring vertically to about 3000 m (9800 feet). Aircraft flights and DIAL operations were successfully conducted between July 14 and 22, 1993, west of Davis, California.

On two days (13 and 23 July, 1993) aircraft profiles were taken near and above the Sutter Buttes to provide information on the vertical and horizontal variability of ozone in the vicinity of a ground based ozone monitor located on South Sutter Butte near the 700m (2,300 foot) elevation. On September 9, 1993, vertical profiles and horizontal transects were flown over the Sierra foothills east of Sacramento to obtain three dimensionally distributed data to aid the ARB Control Strategy Modeling Section in analyzing results from photochemical modeling simulations. The aircraft operations and data acquired are described in this report. Data summaries are presented in graphical form.

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SUMMARY AND CONCLUSIONS:

Flights were conducted on 10 days in July and one day in September 1993. On July 12, test flights were conducted to establish the best flight routes and to verify instrument performance. On July 13 and 23 flights over and near the Sutter Buttes were conducted to assess the spacial variability of ozone concentrations there. Flights on July 14-16 and 19-22 (two to four flights per day) were devoted to collecting data for comparison with DIAL data. On September 9, an extended flight was conducted along the route Davis, Folsom, Placerville, Auburn, Colfax, Auburn, Folsom and return to Davis. This last flight was undertaken to map low altitude ozone variability to aid the evaluation of model simulations.

Variables measured included pressure (altitude), temperature, relative humidity, ozone concentration, and particle number concentrations for aerodynamic diameters greater than 0.3 μm and for diameters greater than 3.0 μm. Aircraft position, heading and airspeed were also recorded. Human error resulted in the loss of ozone data on flight 2 of July 15. The 0.3 channel of the particle counter began malfunctioning on or about July 19. The LORAN position data were lost for several flights on July 12,13,and 14. Otherwise all instrumentation functioned well and all remained within calibration limits.

The DIAL comparison flights were conducted under conditions of relatively low ozone concentrations, typically less than 90 ppbv. The data for the primary variables recorded (T, P, RH, O_3) were averaged within layers 30 meters thick for each flight and have been sent to NOAA/WPL investigators for comparison with the DIAL measurements. Preliminary comparison of one flight's data with DIAL ozone determinations showed very good qualitative agreement but with the DIAL concentrations 10 ppb lower than the aircraft measured values. As of this writing, no additional comparison results have been reported to us.

The first flight (July 13) over the Sutter Buttes recorded a distinct difference between ozone concentrations, with higher values on the southern, and upwind side. On July 23rd relatively pollution free air from the north was present with no differences in ozone concentrations detected among locations near the buttes.

The foothill data were taken during perhaps the highest ozone concentration episode of the year. Ground stations recorded ozone concentrations in excess of 130 ppbv while the aircraft detected a layer 300 meters above ground with over 165 ppbv.

PROJECT DETAILS:

Aircraft instrumentation:

The primary objective of this study was to determine the utility and limitations of the ozone DIAL system in realistic field conditions. Over the past several years we have developed a compact high quality instrumentation system for use in light aircraft. The components of this system relevant to this study are listed in Table 1. Recently we have modified a Dasibi 1008 ozone analyzer to make it solely DC powered, eliminating the need for a heavy, inefficient DC to AC invertor. The modification eliminated the AC power supply by using batteries to provide the various unregulated voltages the AC supply would normally provide. These changes do not affect the measurements themselves, since the standard units are internally DC devices. The results of extensive calibration checks in our laboratory with this instrument are indistinguishable (±1%) from those using a standard instrument. Sample air to the analyzer was drawn through a Teflon tube (2 meters long) inserted through the aircraft ventilation system. The 1008 measures the pressure and temperature in the sample volume and automatically corrects the concentration to sea level pressure at 23°C, for altitudes ≤ 10,000 feet.

The particle counter listed in Table 1 is also DC powered and was manufactured for us by CLIMET instruments. It simultaneously measures in two size ranges, 0.3 and 3 micron diameters. Sampled air is drawn through a small orifice, also mounted in the aircraft ventilation inlet and extending 15 cm out into the oncoming air. The orifice is sized to allow isokinetic sampling at an air speed of 50 ms^{-1}.

The data acquisition system uses a lap-top personal computer and an external, 16 channel multiplexer and a 12 bit analog to digital converter. The scan frequency and channel selection are software controlled with a maximum sampling rate of 15 hertz. Graphical display of the data sampled is shown on the computer screen in real time during the flight to allow the pilot to monitor both the state of the instrumentation and the conditions being measured. The LORAN-C position data, signal levels and quality control information are sampled periodically via the RS-232 serial input port of the computer. Flight log and relevant information is recorded in flight using a voice tape recorder. The system ingests information until either the operator terminates a file or the maximum number of samples is reached. The computer then writes the data to a data file, recycles and reinitiates data acquisition. The output and recycling time requires about 1 minute.

The remaining instrumentation is standard. The temperature, relative humidity and air speed sensors are mounted on a strut under the wing, clear of the exhaust, propeller wake and disturbed flow around the aircraft surfaces.

Temperature, humidity and ozone instruments were calibrated at the beginning and end of the July flights using portable transfer standards. The absolute accuracy of these instruments is listed in Table 1. The ozone meter calibration results are shown in Figure 1. The position information is checked at each takeoff and landing, as is the pressure sensor and the correction for a non-standard pressure (altimeter setting). The pressure computed altitudes are compared with the visually read aircraft altimeter, to provide a check on the altitude calculation. The particle counter is not regularly calibrated but the laser diode detector is checked periodically and if within specified limits, the device is assumed to be in calibration.

DIAL Comparison flights:

The NOAA-WPL ozone DIAL system was installed west of Yolo County Airport during the second week of July, 1993. On days when the LIDAR was operating, we executed ascending and descending spirals in the same air space sampled by the LIDAR. The spirals have diameters of about two miles. Since the DIAL data is time averaged data from a vertically pointing instrument, the aircraft data should be time averages. Since the Dasibi has a cycling period of about 10 seconds, slow vertical speeds were used to obtain optimal vertical resolutions. For this reason climb and descent rates were held to less than 500 feet per minute allowing ozone readings every 25 vertical meters or less. Plots of vertical profiles of primary variables are given in Appendix A. They are self explanatory. Note that the larger "gaps" in the ozone profile shown in some profiles (e.g. July 19, 15:19 to 15:55) are due to recycling of the data acquisition system between files while the aircraft passes through a sharp discontinuity in the ozone profile. A list of data files for all flights undertaken is presented in Table 2. Note also that the altitudes given in Table 2 are the starting and ending altitudes *not necessarily* the vertical range. Data from the DIAL comparison flights, averaged over 30 meter layers, were sent to NOAA-WPL staff on September 30, 1993.

Sutter Buttes Flights:

The intent of these flights was to obtain vertical profiles upwind, downwind and over the Buttes to describe the spatial variability of ozone there. The reason for this was to evaluate how well the ground based monitor installed on the Buttes represents conditions at the altitude of the monitor but over the valley. The flight paths for the two days are shown in Figures 2a and 4a. For the July 13 flights, visual observations of smoke plumes in the area indicated the wind near the ground was from the southeast, while aloft (> 400 m) the wind appeared to be from the north ±30°. On July 23, winds at all altitudes appeared to be from the north or northwest. Data reported by the surface instrument for the flight times are given in Table 3.

July 13,1993:

Vertical profiles of temperature, relative humidity, ozone and particles greater than 0.3 μm diameter for July 13,1993 are shown in Figure 2b,c,d and Figure 3. The ozone concentrations SE of the Buttes and below 1200 m were between 70 and 90 ppb (Fig 2b), while to the NW concentrations were about 60 ppb (Fig 2c). The profile over the Buttes (Fig. 2d) shows an oscillation between the two "air masses". Since the aircraft spiraled down over the Buttes, part of the data were taken south of the crest and part north of the crest. Figure 3 is a time plot of several variables for this spiral, including heading and ozone concentration. The peak ozone concentrations and relative humidity values are found as the aircraft moves to the NW corner of the Buttes area (westerly and initial southerly headings). We interpret these to be plumes passing through the topographic saddle between the center and western peak of the Buttes.

July 23, 1993:

The flight track and vertical profiles for July 23, 1993 are shown in Figure 4. On this date the relative humidities are higher than on July 13, but the low altitude ozone concentrations are much lower. With the prevailing north wind, the low ozone concentrations were expected. There is also very little difference in the ozone concentrations below 1500 meters among the profiles and hence there is no systematic variation in ozone across the Buttes.

Foothills flight:

The flight tracks for September 9, 1993 are shown in Figures 5a, 6a, and 7a. These routes were flown in conformance with the request by personnel of the ARB modeling section. On this day the highest ozone concentrations among all the observational days were seen. Vertical layering of ozone is clearly seen in Figures 5b, 6c,d and 7c. By early afternoon (Figure 7c, 1430 PDT) a layer of very high ozone concentrations was present east of Folsom below 800m. A high concentration plume (145 ppb, Fig. 6b) was also found at about at 1250 PDT and 8km SE of Auburn on the transect from Placerville to Auburn. Concentrations between Auburn and Colfax were about 125 ppb (Fig. 6d and e). Ground level monitors in the area also recorded high ozone concentrations on the afternoon of September 9. The times of day and range of concentrations observed are listed in Table 4. While the peak values measured aloft by the aircraft exceed the hourly averaged ground level values, the overall pattern of concentration data is self consistent. We note that ozone concentrations at Auburn did not exceed 80 ppb on September 9, but reached 120 ppb on the next afternoon.

TABLE 1

UCD AIRCRAFT INSTRUMENTATION SYSTEM

VARIABLE	SENSOR TYPE	MANUFACTURER	USEFUL RANGE	ACCURACY
PRESSURE (ALTITUDE)	CAPACITIVE	SETRA	-100' - 12,000'	± 0.3 MB (± 3M)
TEMPERATURE	PLATINUM RTD	YELLOW SPRINGS INSTRUMENTS	-20 - 50°C	± 0.2°c
RELATIVE HUMIDITY	CAPACITIVE	QUALIMETRICS	10 - 98%	± 3%
AIR SPEED	THERMAL ANEMOMETER	T.S.I.	30 - 150 KNOTS	± 0.4 MS^{-1}
HEADING	DIRECTIONAL GYRO	-----	180 - +180°	± 2 DEGREES
POSITION	LORAN-C	TTOMARROW	LAT. AND LON.	0.02 MIN
PARTICLE CONCENTRATION	OPTICAL COUNTER	CLIMET	d > 0.3 μm d > 3.0 μm	± 2% of count
OZONE CONCENTRATION	U.V. ABSORPTION	DASIBI 1008 DC POWERED	0 - 999 ppbv	3ppb

TABLE 2
FLIGHT DATA FILES:

File ID Date, No.	Time (PDT) Start		End	Altitude (m. MSL) Starting		Ending	Comments
TEST FLIGHTS:							
JUL12-02	11:11:15	TO	11:27:49	213.4	TO	2410.7	NO LORAN DATA
JUL12-04	11:50:32	TO	11:52: 1	2347.0	TO	2101.3	"
JUL12-05	11:54: 0	TO	11:54:35	1999.5	TO	1999.2	"
JUL12-06	12:19:28	TO	12:22:37	19.8	TO	2596.6	"
JUL12-07	12:26: 5	TO	12:29:52	19.8	TO	21.9	GROUND TEST
JUL12-11	14:51:39	TO	15: 8:12	19.8	TO	2247.9	
JUL12-12	15:13:33	TO	15:34:18	2069.6	TO	711.4	
JUL12-13	15:35:15	TO	15:43:55	731.5	TO	17.1	
SUTTER BUTTES COMPARISONS:							
JUL13-01	13:49:55	TO	14: 2:40	19.8	TO	27.7	GROUND TEST
JUL13-03	14: 6:22	TO	14:19:41	152.4	TO	2098.5	TRAVERSE FROM DAVIS
JUL13-04	14:41:39	TO	14:55:34	2133.6	TO	310.3	SPIRAL SE OF BUTTES
JUL13-05	14:56:55	TO	15: 5:17	243.8	TO	115.2	TRAVERSE WEST SIDE
JUL13-07	15: 6:16	TO	15:17:53	289.6	TO	1823.6	SPIRAL NW OF BUTTES
JUL13-08	15:19:59	TO	15:39:17	1828.8	TO	755.9	SPIRAL OVER BUTTES
JUL13-09	15:40:21	TO	15:59:17	899.2	TO	905.6	RETURN TO DAVIS
JUL13-10	16: 2:27	TO	16:11:56	902.2	TO	31.4	
DIAL COMPARISONS:							
JUL14-21	8:42:34	TO	8:54:17	19.8	TO	32.6	DAVIS TO YOLO
JUL14-22	8:58:32	TO	9:12:22	365.8	TO	2317.7	
JUL14-23	9:13:32	TO	9:34:15	1984.2	TO	197.5	
JUL14-24	9:35:11	TO	9:46:39	152.4	TO	123.7	
JUL14-31	11:15:59	TO	11:36:18	45.7	TO	1823.6	
JUL14-32	11:37:48	TO	11:44: 0	1828.8	TO	2498.1	NO LORAN DATA
JUL14-33	11:55:17	TO	12:15:14	2017.8	TO	354.5	"
JUL14-41	14:26: 3	TO	14:31:33	19.8	TO	18.3	GROUND TEST
DIAL COMPARISONS:							
JUL15-02	7:26:51	TO	7:35:24	19.8	TO	615.4	ABORT: TEMP. SENSOR
JUL15-03	7:49: 7	TO	7:50:26	29.9	TO	30.5	GROUND TEST
JUL15-04	7:56:14	TO	8:10:19	29.9	TO	1983.6	
JUL15-05	8:11:43	TO	8:28:36	1935.5	TO	1362.2	
JUL15-06	8:48:50	TO	8:59:48	914.4	TO	399.0	
JUL15-12	11: 1:41	TO	11:14: 1	19.8	TO	34.7	FALSE OZONE SWITCH
JUL15-13	11:17: 3	TO	11:30:13	29.9	TO	1984.6	"
JUL15-14	11:31:52	TO	11:47:28	1981.2	TO	1371.3	"
JUL15-15	11:48:53	TO	12: 1:42	1371.6	TO	45.4	"
JUL15-21	14:23:13	TO	14:43:47	19.8	TO	1227.1	
JUL15-22	14:44:48	TO	14:56:57	1219.2	TO	2279.0	
JUL15-23	14:58:35	TO	15:15:48	2316.5	TO	41.1	

Table 2 (continued)

DIAL COMPARISONS:						
JUL16-01	7:16:56 TO 7:20:46	19.8	TO	25.0	DAVIS TO YOLO
JUL16-02	7:28:12 TO 7:45:55	19.8	TO	926.6	
JUL16-03	7:46:50 TO 8: 2:25	917.4	TO	2764.2	
JUL16-04	8: 3:23 TO 8:10:49	2776.7	TO	3358.0	
JUL16-05	8:12: 1 TO 8:29:43	3413.8	TO	449.9	
JUL16-06	8:30:43 TO 8:38: 8	460.2	TO	22.9	
DIAL COMPARISONS:					
JUL19-01	9:45:16 TO 9:53:54	19.8	TO	15.5	GROUND TEST
JUL19-02	10: 1:46 TO 10:22:30	19.8	TO	24.1	ABORT, DIAL NOT UP
JUL19-03	11:36: 6 TO 11:52: 8	19.8	TO	2146.7	
JUL19-04	11:53:16 TO 12: 6:50	2133.6	TO	3355.5	
JUL19-05	12: 7:58 TO 12:23:39	3383.3	TO	902.2	
JUL19-06	12:25:13 TO 12:35: 5	914.4	TO	46.9	
JUL19-11	14:28: 6 TO 14:40:53	19.8	TO	28.7	DAVIS TO YOLO
JUL19-12	14:42:25 TO 14:58: 9	29.9	TO	2136.3	LATE ON P-COUNTER
JUL19-13	14:59: 3 TO 15:16:45	2126.0	TO	3402.2	
JUL19-14	15:18:36 TO 15:34:57	3518.9	TO	900.7	
JUL19-15	15:36: 4 TO 15:54:41	914.4	TO	35.4	
DIAL COMPARISONS:					
JUL20-01	7:40:25 TO 7:58:23	19.8	TO	1371.3	
JUL20-02	7:59:27 TO 8:19:28	1356.4	TO	3191.9	
JUL20-03	8:23:10 TO 8:38:55	3352.8	TO	916.5	
JUL20-04	8:40:11 TO 8:58:27	914.4	TO	16.8	
JUL20-11	10:54:39 TO 10:58:45	19.8	TO	22.6	GROUND TEST
JUL20-12	11: 3: 9 TO 11:13:51	19.8	TO	31.7	DAVIS TO YOLO
JUL20-13	11:17:31 TO 11:33:43	29.9	TO	2291.2	
JUL20-14	11:35: 6 TO 11:45:53	2272.6	TO	3209.2	
JUL20-15	11:49:20 TO 12:10: 3	3397.9	TO	187.1	
JUL20-16	12:10:57 TO 12:11:41	19.8	TO	26.5	GROUND TEST
JUL20-21	14:25:14 TO 14:30: 2	19.8	TO	20.4	"
JUL20-22	14:31:15 TO 14:43:11	19.8	TO	32.3	DAVIS TO YOLO
JUL20-23	14:46:54 TO 15: 6:26	29.9	TO	2515.2	
JUL20-24	15: 7:37 TO 15:14: 9	2515.2	TO	3043.7	
JUL20-25	15:16:17 TO 15:36: 9	3148.9	TO	252.7	
Jul20-26	15:37:14 TO 15:47:15	327.4	TO	27.1	
DIAL COMPARISONS:					
JUL21-01	7:40:30 TO 7:51: 8	19.8	TO	29.6	DAVIS TO YOLO
JUL21-02	7:55: 3 TO 8: 7: 4	29.9	TO	1840.4	
JUL21-03	8: 8: 1 TO 8:24:12	1828.8	TO	3346.4	
JUL21-04	8:25:24 TO 8:36:50	3352.8	TO	1227.7	
JUL21-05	8:37:33 TO 8:46: 2	1164.3	TO	77.4	
JUL21-06	8:46:37 TO 8:53:35	221.0	TO	18.9	

Table 2 (continued)

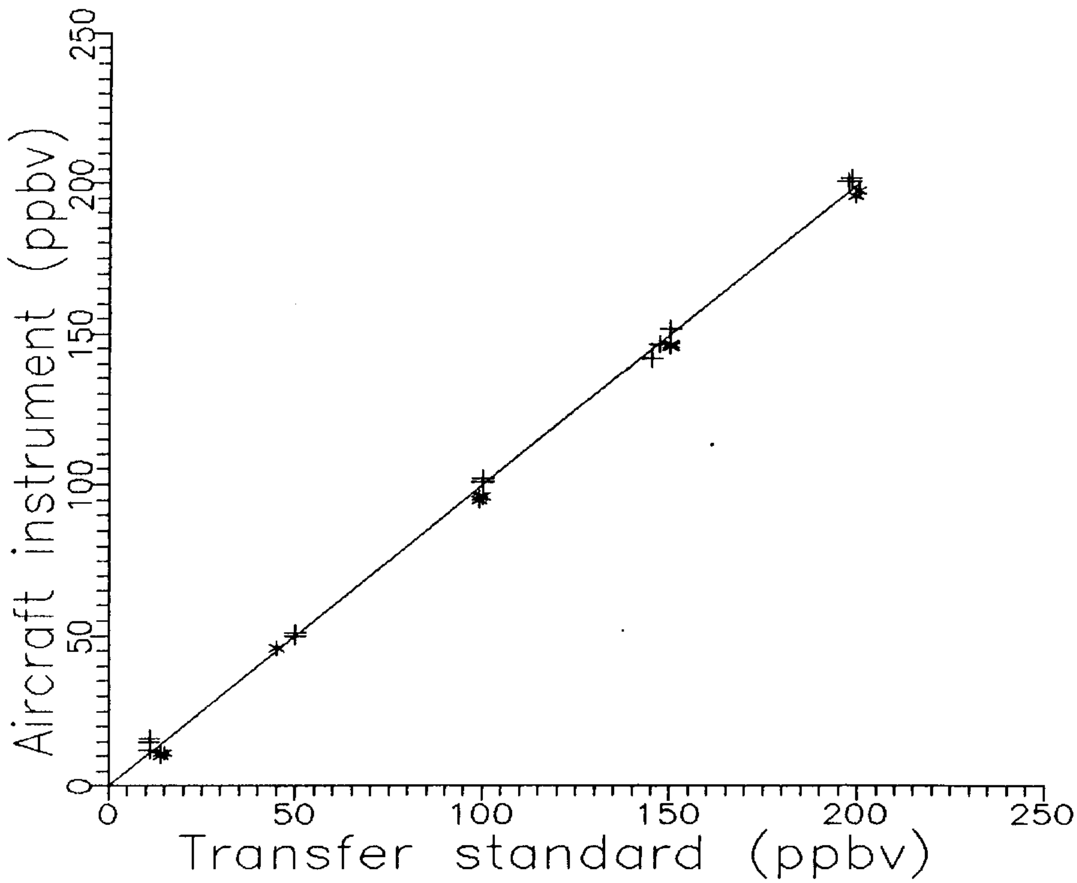
JUL21-11	10:56: 6 TO 11: 6:44	19.8 TO 27.4	DAVIS TO YOLO, NO LORAN
JUL21-12	11:11:58 TO 11:23:20	29.9 TO 1829.1	
JUL21-13	11:28: 9 TO 11:42:56	1828.8 TO 3317.1	
JUL21-14	11:44: 1 TO 11:56: 5	3322.3 TO 1184.8	
JUL21-15	11:56:58 TO 12: 5:36	1219.2 TO 71.9	
JUL21-16	12: 6:17 TO 12:12:35	216.4 TO 19.5	
JUL21-21	14:42: 6 TO 14:45:36	19.8 TO 20.1	GROUND TEST
JUL21-22	14:49: 5 TO 14:59:17	19.8 TO 34.4	DAVIS TO YOLO
JUL21-23	15:15:29 TO 15:33:41	29.9 TO 2288.1	
JUL21-24	15:34:40 TO 15:42:43	2286.0 TO 2909.0	
JUL21-25	15:44:21 TO 15:57:59	2987.0 TO 885.7	
JUL21-26	15:59:19 TO 16: 9: 0	914.4 TO 320.3	
JUL21-31	20:31:50 TO 20:49:11	19.8 TO 35.1	DAVIS TO YOLO
JUL21-32	20:56:48 TO 21:15:25	29.9 TO 2297.9	
JUL21-33	21:17:41 TO 21:36:53	2286.0 TO 1663.0	
JUL21-34	21:38: 8 TO 21:53:53	1679.4 TO 31.1	
DIAL COMPARISONS:			
JUL22-01	10:13:26 TO 10:24:56	19.8 TO 36.0	DAVIS TO YOLO
JUL22-02	10:29:12 TO 10:48:22	29.9 TO 2442.4	
JUL22-03	10:49:40 TO 11: 8: 0	2438.4 TO 1053.7	
JUL22-04	11: 8:58 TO 11:20: 5	1066.8 TO 31.4	
JUL22-11	13:17:26 TO 13:30: 4	19.8 TO 31.7	DAVIS TO YOLO
JUL22-12	13:33: 0 TO 13:51:20	29.9 TO 2324.7	
JUL22-13	13:52:24 TO 14: 1:38	2286.0 TO 3053.2	
JUL22-14	14: 2:50 TO 14:23:34	3139.4 TO 50.6	
SUTTER BUTTES COMPARISONS:			
JUL23-01	9:21: 4 TO 9:22:41	19.8 TO 18.9	GROUND TEST
JUL23-02	9:26:31 TO 9:46:41	19.8 TO 1990.6	DAVIS TO BUTTES
JUL23-03	9:49:47 TO 10:10:24	1981.2 TO 1956.2	
JUL23-04	10:11:31 TO 10:28:43	1981.2 TO 777.8	SPIRAL, NW OF BUTTES
JUL23-05	10:35:28 TO 10:46:35	304.8 TO 1695.6	SPIRAL, SE OF BUTTES
JUL23-06	10:48: 1 TO 11: 8:34	1706.9 TO 1055.2	SPIRAL OVER BUTTES
FOOTHILL MODEL COMPARISONS:			
SEP09-01	11:27: 5 TO 11:47: 0	19.8 TO 2000.1	DAVIS TO FOLSOM
SEP09-02	11:49:44 TO 12: 9:42	2133.6 TO 1081.1	SPIRAL E OF FOLSOM
SEP09-03	12:11:41 TO 12:23:48	1310.6 TO 1516.1	FOLSOM TO PLACERVILLE
SEP09-04	12:24:53 TO 12:45:34	1615.4 TO 1339.0	SPIRAL PLACERVILLE
SEP09-05	12:46:29 TO 12:58:27	1356.4 TO 1353.9	PLACERVILLE TO AUBURN
SEP09-06	12:59:15 TO 13:13:56	1371.6 TO 2447.2	SPIRAL NEAR AUBURN
SEP09-07	13:15:30 TO 13:36:10	2741.7 TO 1291.4	SPIRAL CONT.;COLFAX
SEP09-08	13:37: 6 TO 13:56:24	1249.7 TO 2172.9	COLFAX-AUBURN-FOLSOM
SEP09-09	13:58: 1 TO 14: 7:49	2011.7 TO 889.1	SPIRAL E OF FOLSOM
SEP09-10	14: 9: 0 TO 14:29:43	807.7 TO 690.7	CONT.; TOWARD DAVIS

TABLE 3
Ground level ozone concentrations at Sutter Buttes

Date	Time (PDT)	Range of Ozone Concentrations (ppbv)
July 13, 1993	13-1500	40-50
	19-2100	60-70
July 23, 1993	10-1100	20
	15-2400	40-50

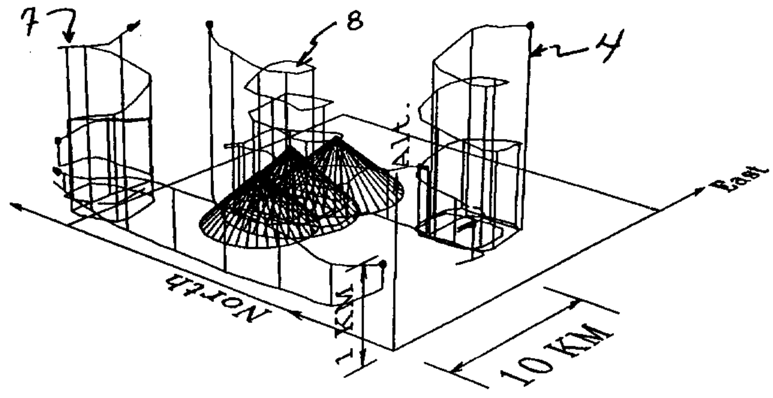
TABLE 4.
Peak ozone concentrations at foothill stations 9/9/93.

Station	Time (PDT))	Range of O_3 concentrations (ppbv)
N. Highlands	13-1800	90-110
Folsom	12-1900	90-140
Placerville	14-2200	90-120
Sly Park L.C.	14-2000	90-120
Roseville	13-1900	90-130
Rocklin	12-1900	90-120
Auburn	10-2000	70-80
Colfax	11-1900	70-80

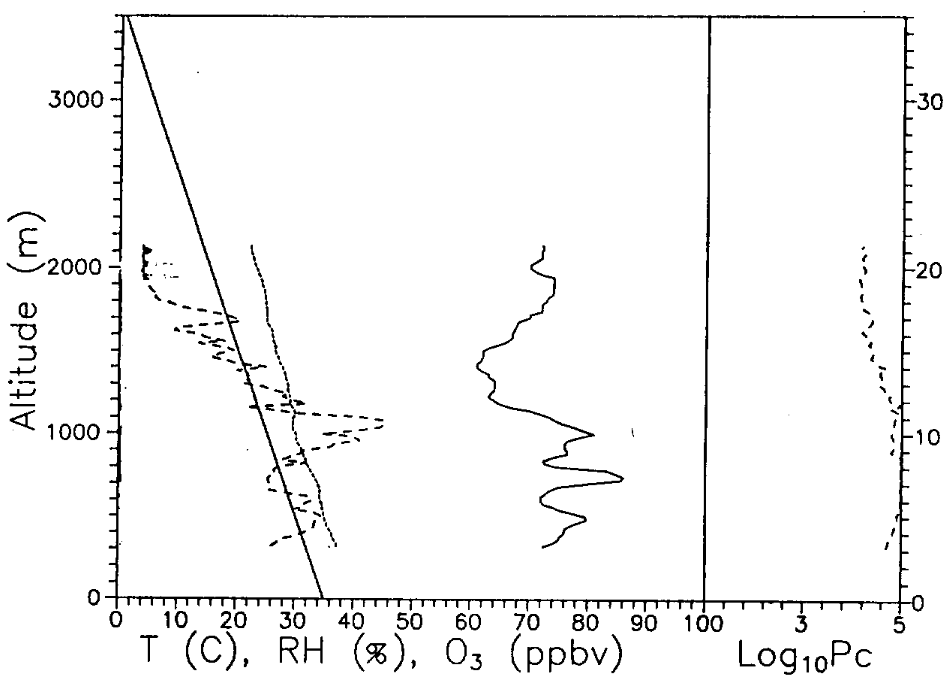


1. Plot of calibration values comparing transfer standard ozone concentrations with those measured by the aircraft DC Dasibi ozone meter. July 10 calibration (*), July 23 calibration (+).

a.



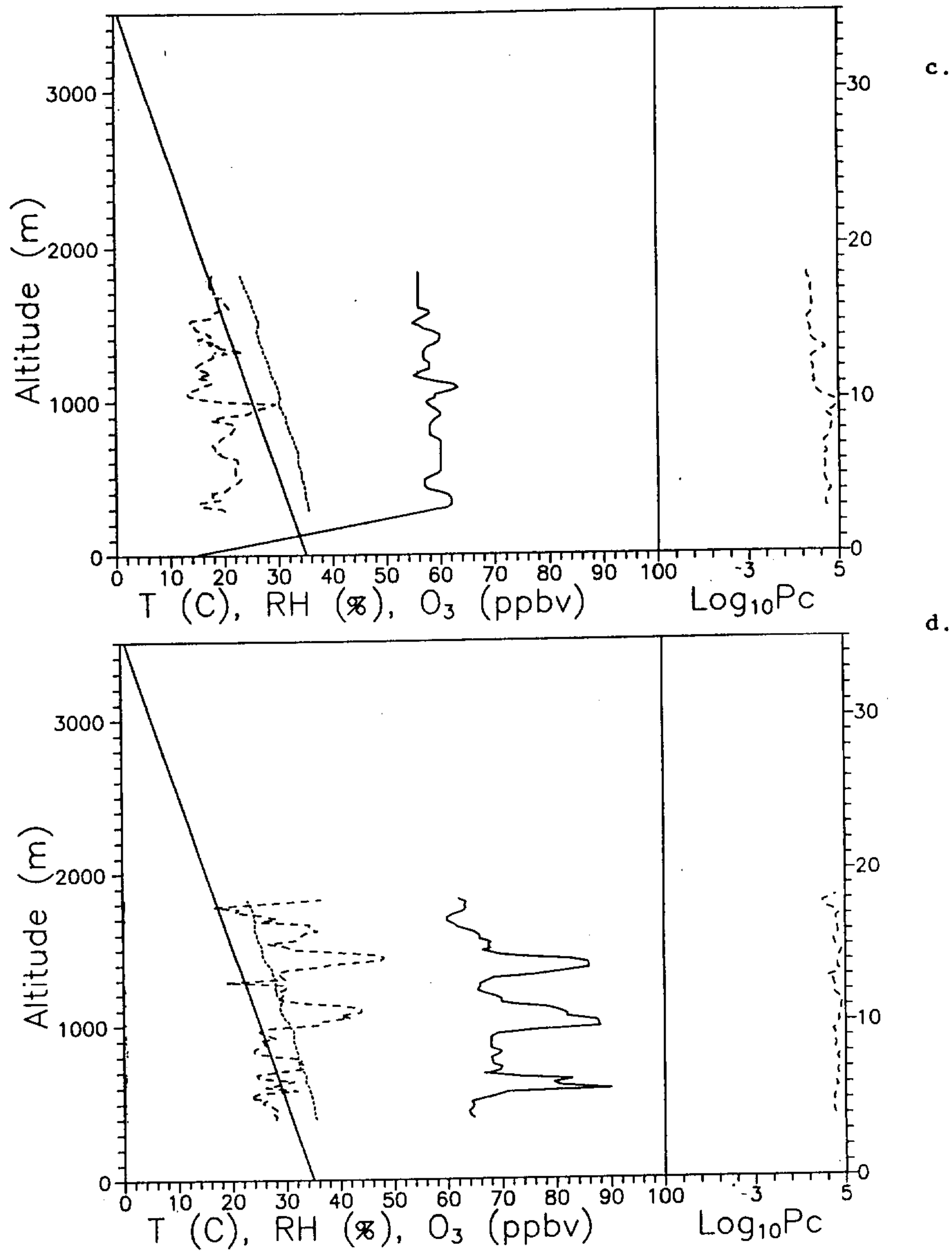
b.



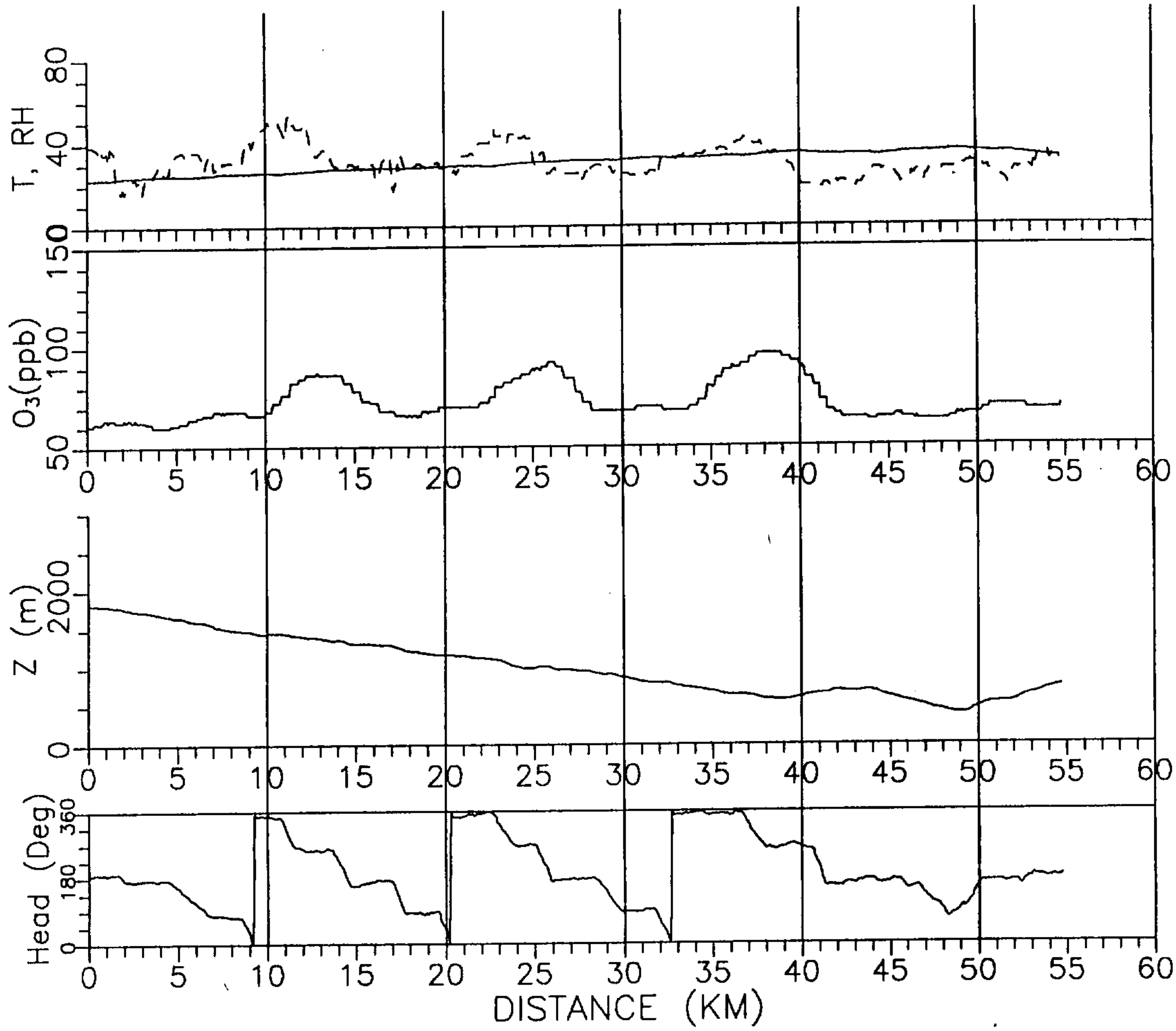
2 a. Plot of the flight track followed for the July 13 flights near the Sutter Buttes, schematically represented by the cones drawn in the figure. Circles mark the starting point of the data file, arrows the ending point. Ground tracks are also shown with vertical lines connecting the ground track with the actual track. Flight tracks are labeled with the data file number for that day.

b. Plot of the July 13 vertical profile of temperature (short-dashed line), relative humidity (longer-dashed line), ozone concentration (solid line), base 10 logarithm of the 0.3 micron particle count (dashed line on right) and turbulence intensity expressed as the sum of the rms variation of air speed and temperature (solid line, left side). Solid straight line angling across plot represents the dry adiabatic lapse rate. Label at top of plot is the date and data file number for the data plotted. Spiral is SE of the Buttes

12.

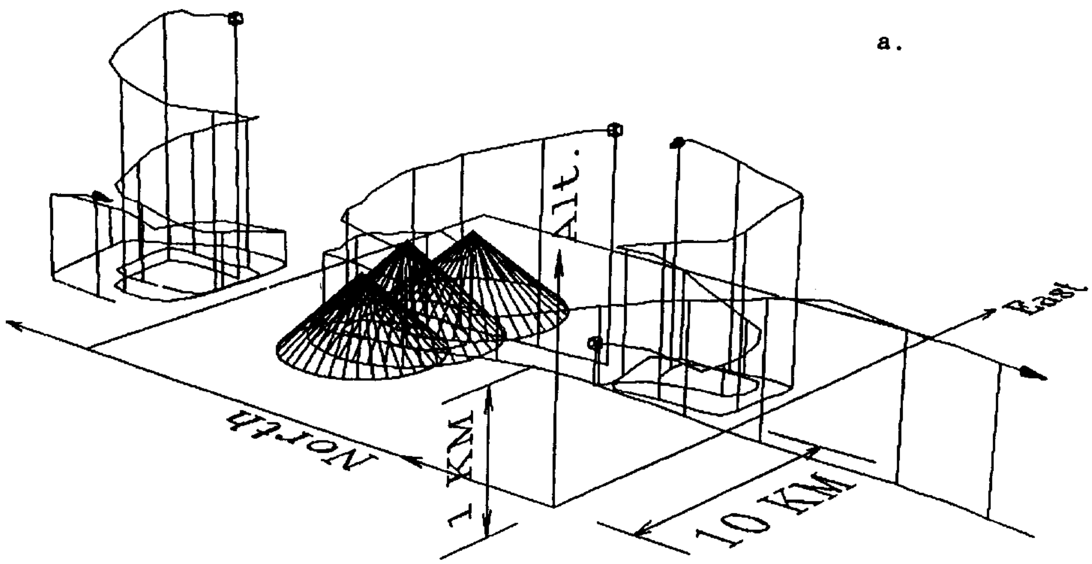


2 c,d. Same as 2b but for spirals NW (c) and over (d) the Buttes.

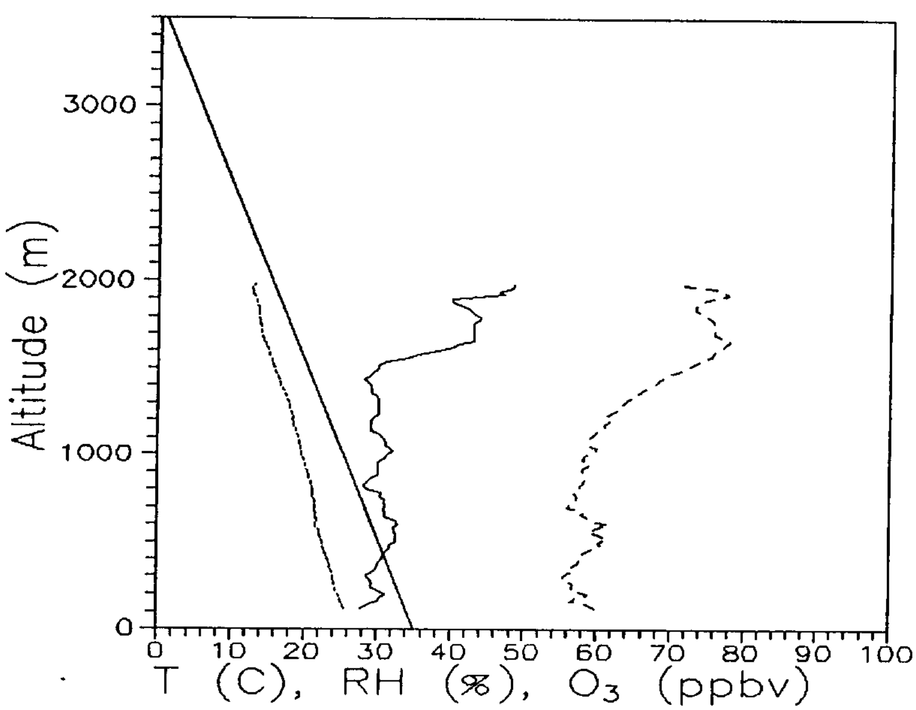


3. Plot of selected variables for July 13 (file 08, 15:20-15:39) over the Sutter Buttes versus time expressed as linear distance traveled by the aircraft. Heading, bottom trace, is the true heading of the aircraft.

a.

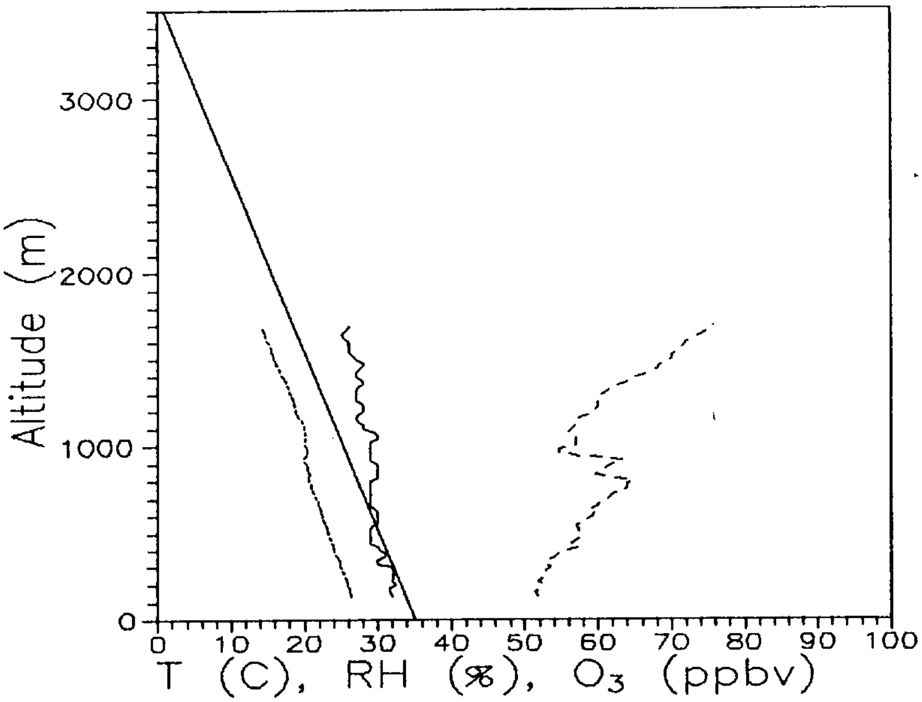


b.

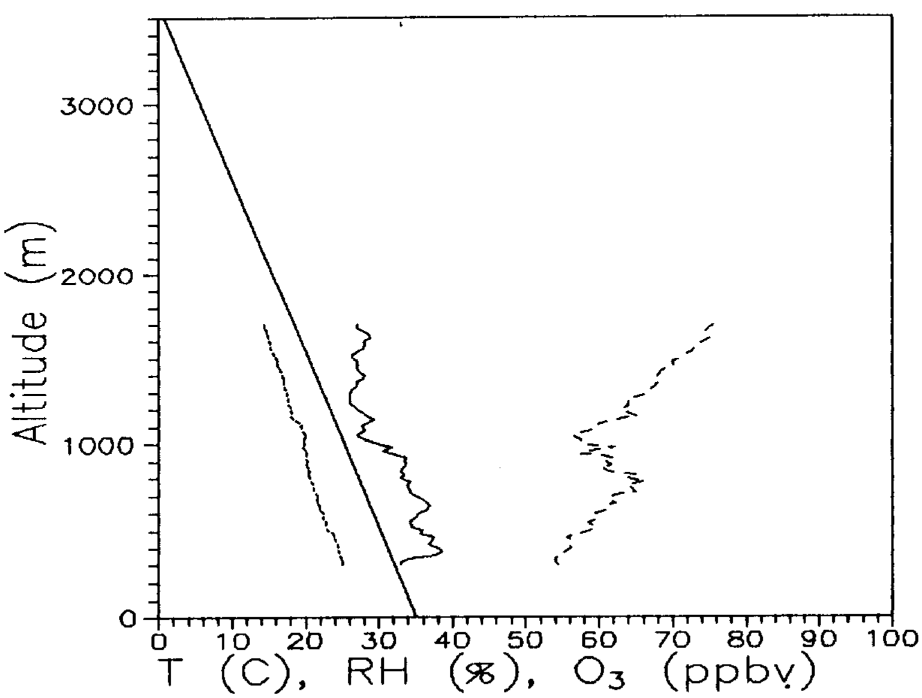


4 a,b. Same as 2a,b but for July 23. Spiral (b) is NW of the Buttes between 10:12 and 10:24.

c.

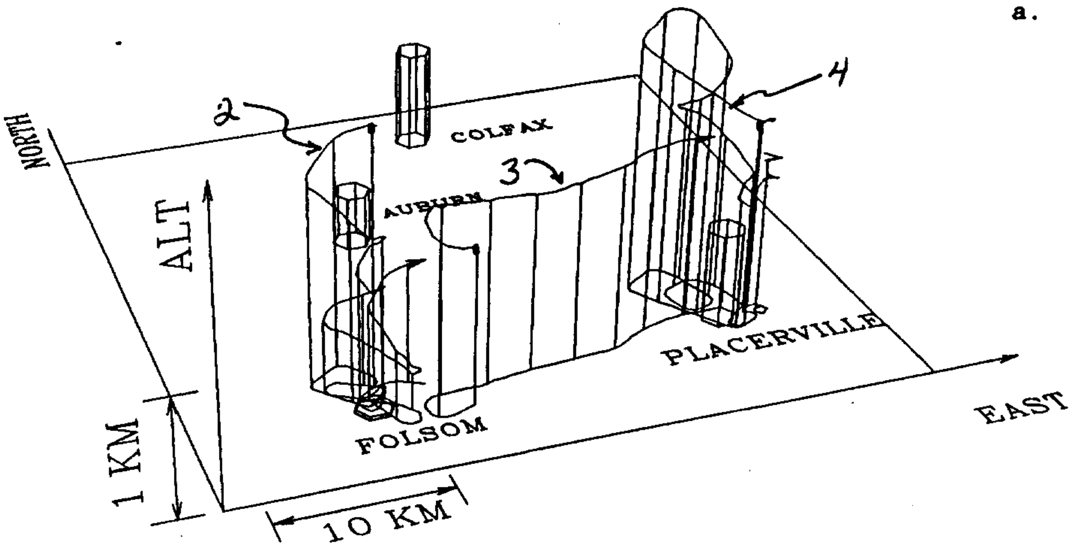


d.

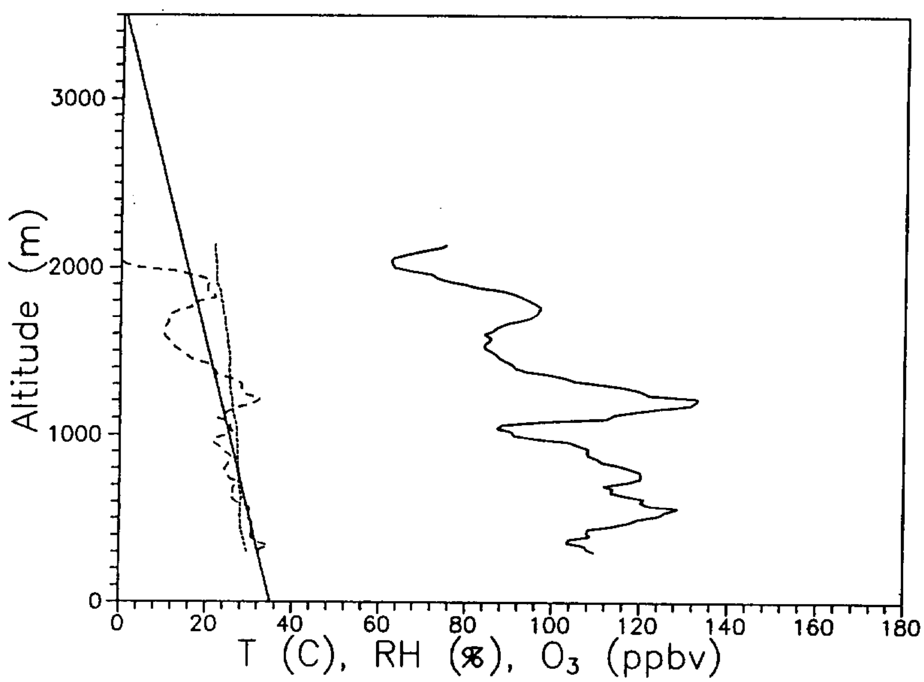


4 c,d Same as 2c,d but for July 23, 1993. Spiral c is between 10:35 and 10:47 SE of the Buttes; d is between 10:48 and 11:09, over the Buttes.

a.



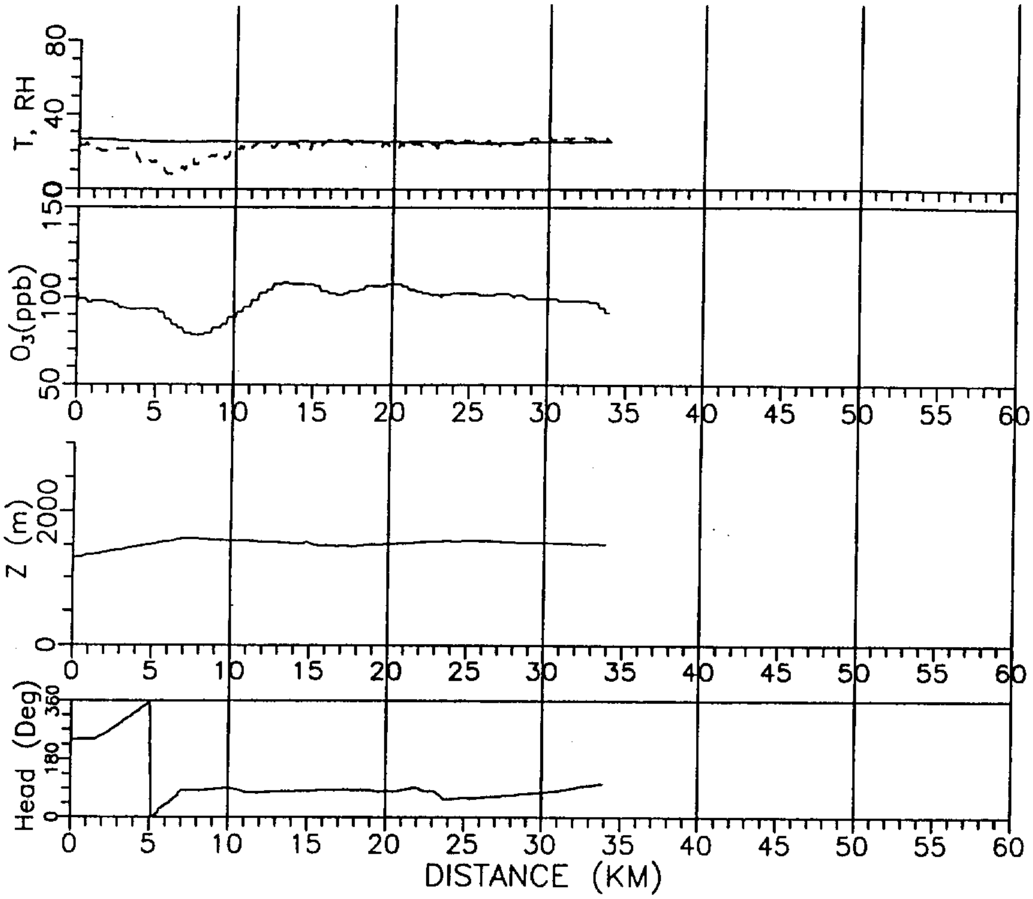
b.



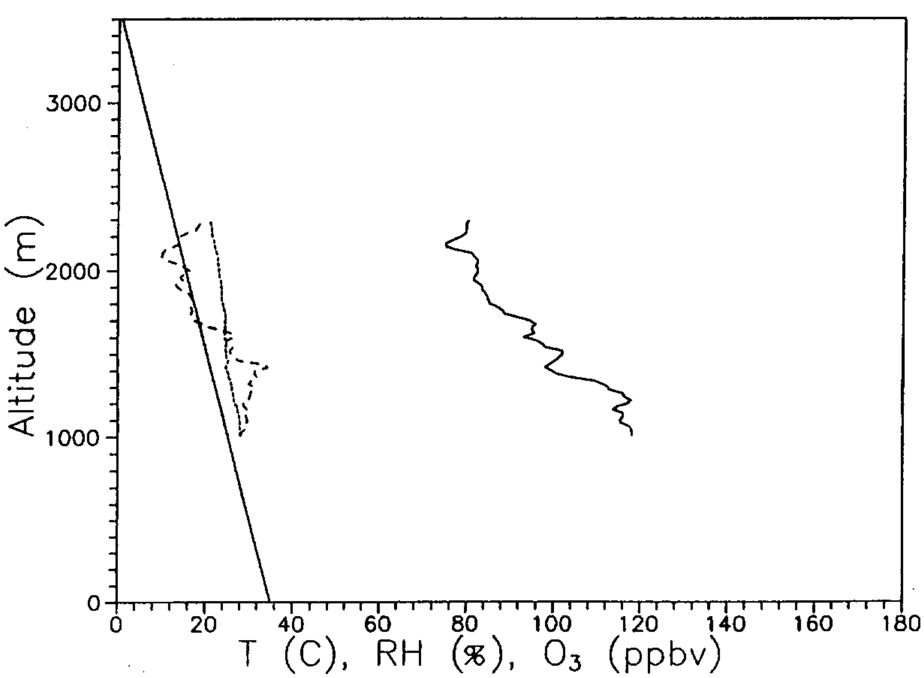
5 a. Flight paths, similar to 2a, for the aircraft on September 9 for data files 2, 3 and 4. Hexagonal columns locate major landmarks. Height of columns indicates altitude of these locations.

b. Vertical profile south of Folsom (11:50-12:10) similar to figure 2b-d, showing ozone (solid) temperature (short-dashed line) and relative humidity (longer-dashed line).

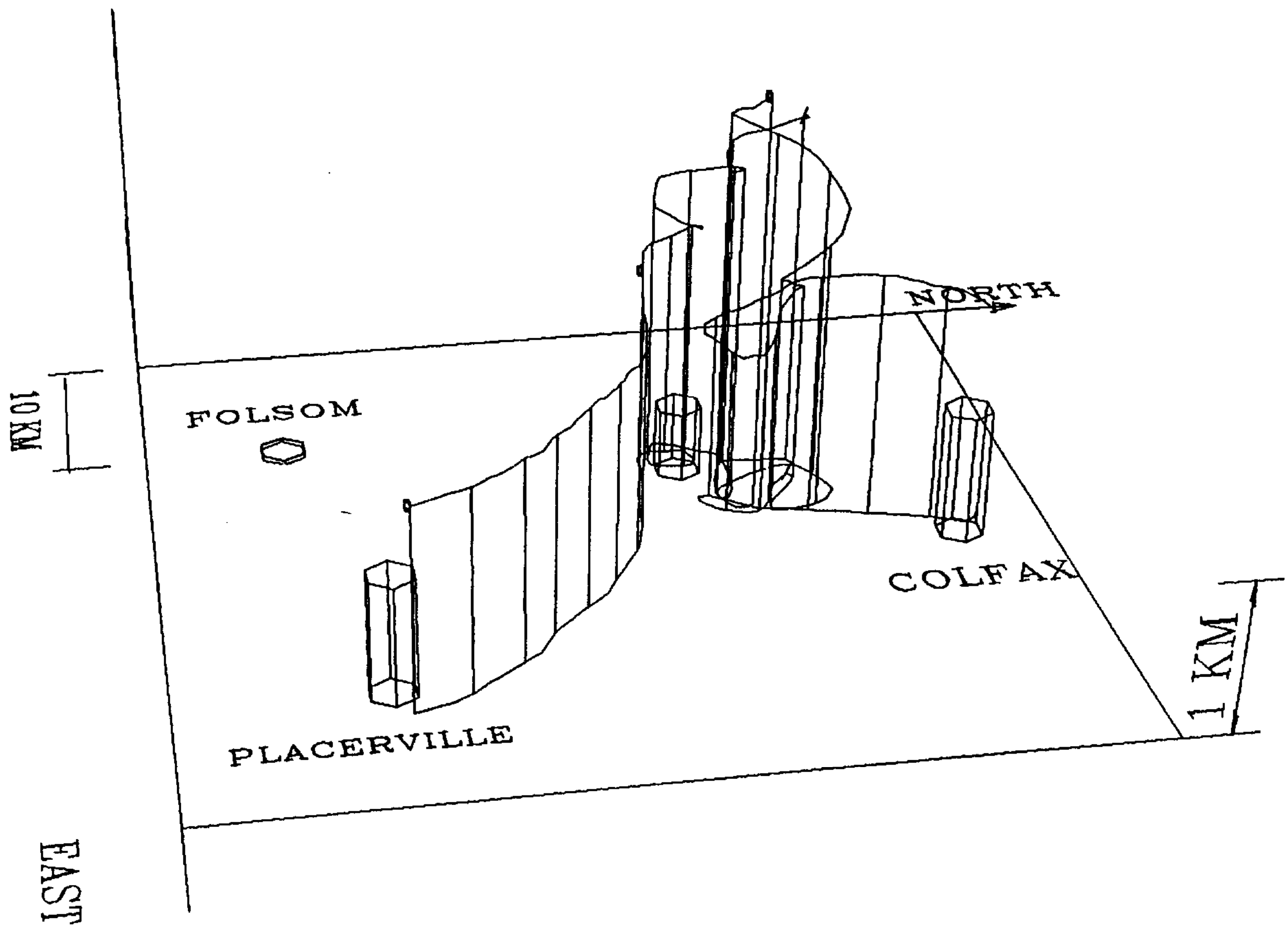
c.



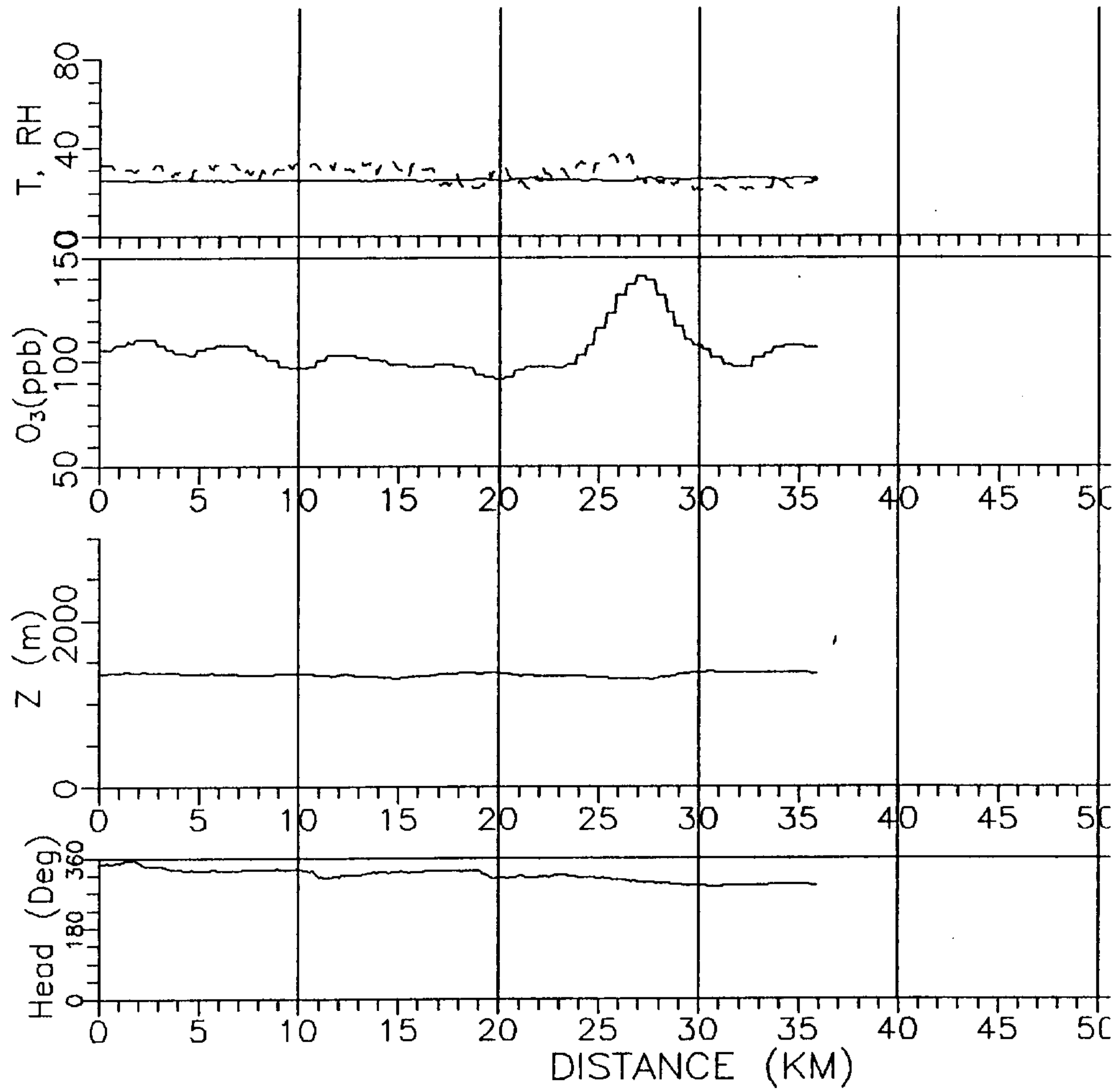
d.



5 c. Same as Figure 3, but for traverse from Folsom to Placerville (12:12-12:24).
d. Same as 5b but over Placerville (12:25-12:46).

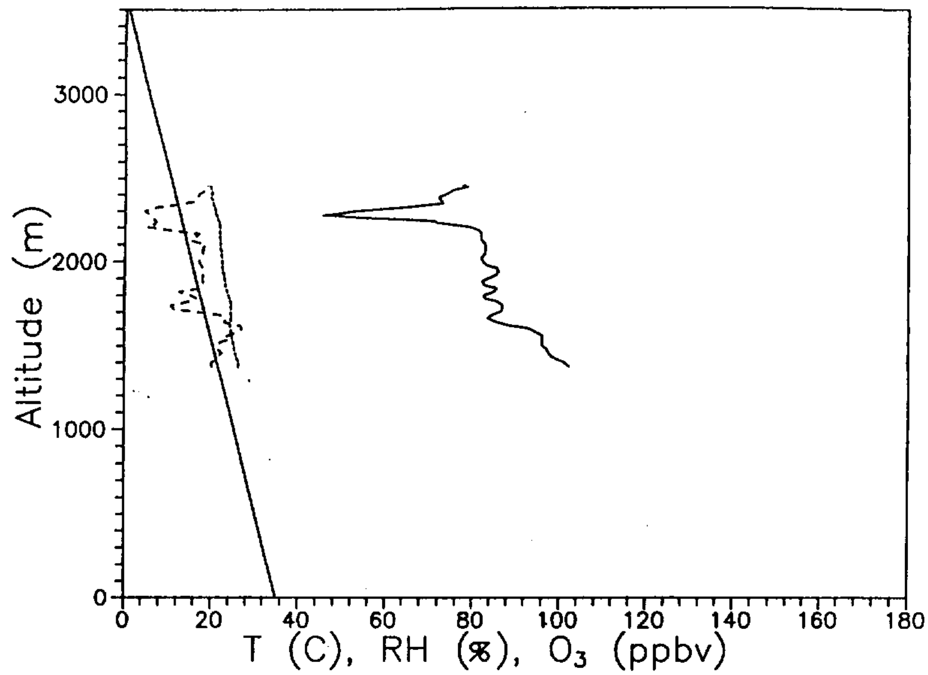


6 a. Same as 5a (September 9) but for files 5, 6, and 7.

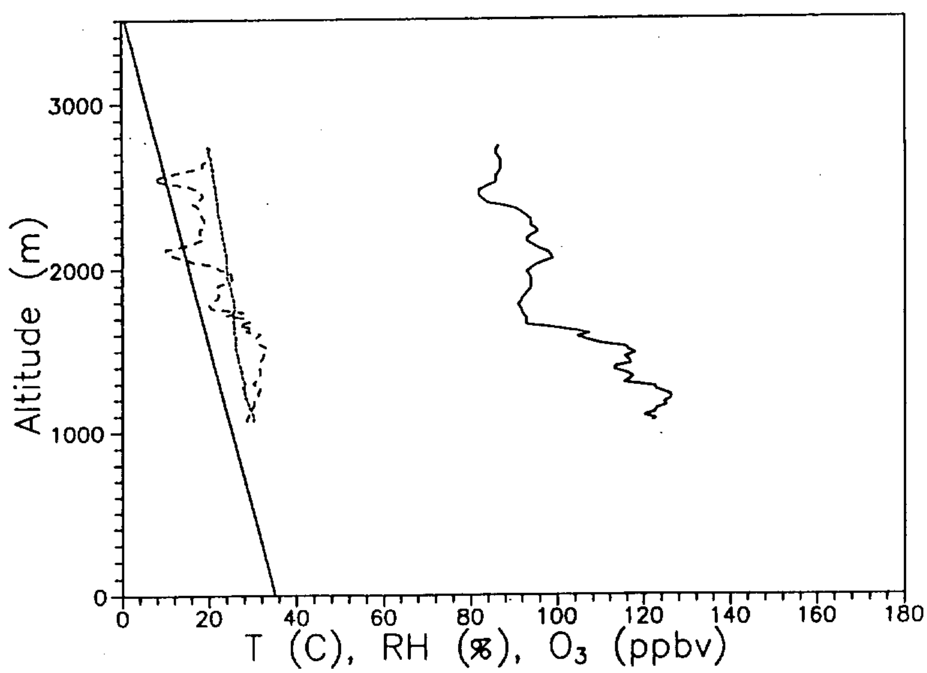


6 b. Same as 5c but for traverse from Placerville to Auburn (12:46-12:58).

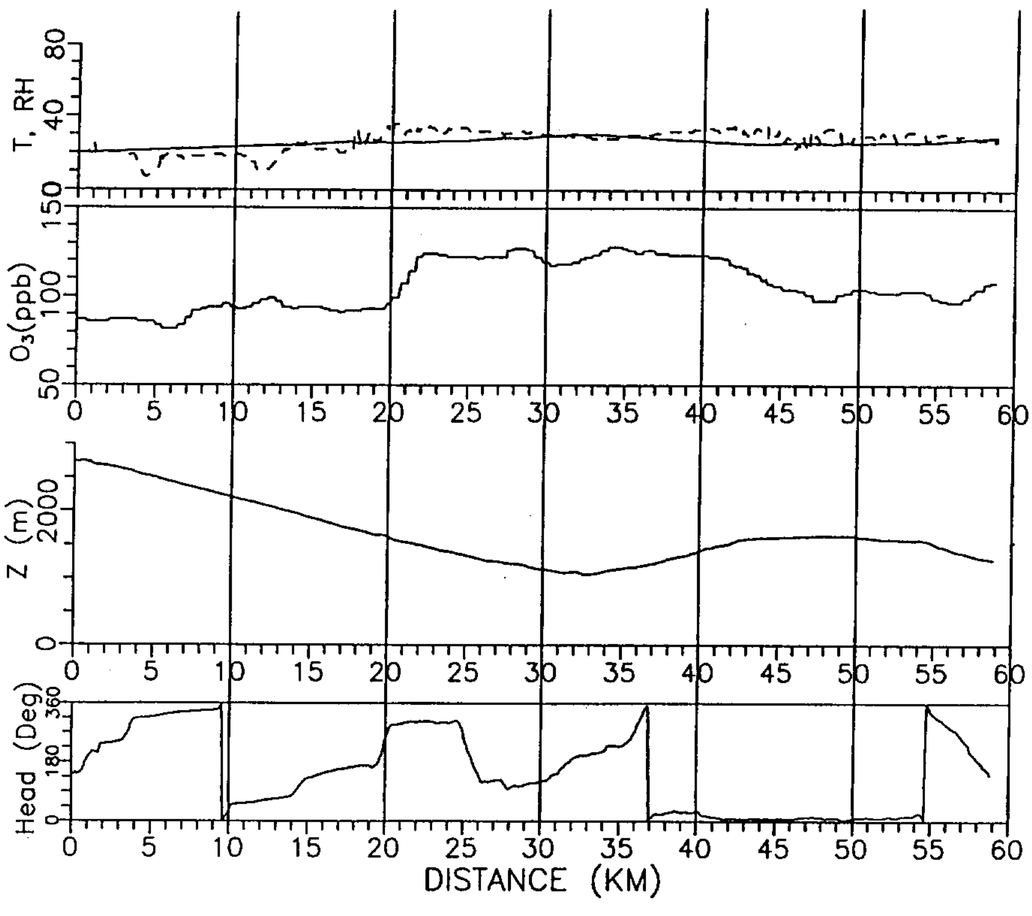
c.



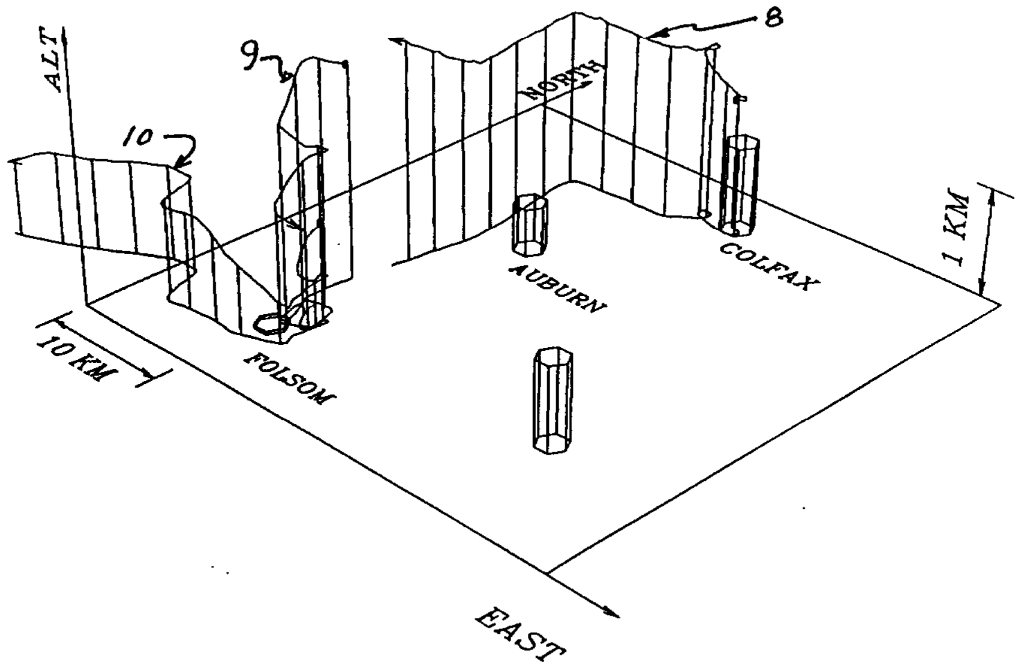
d.



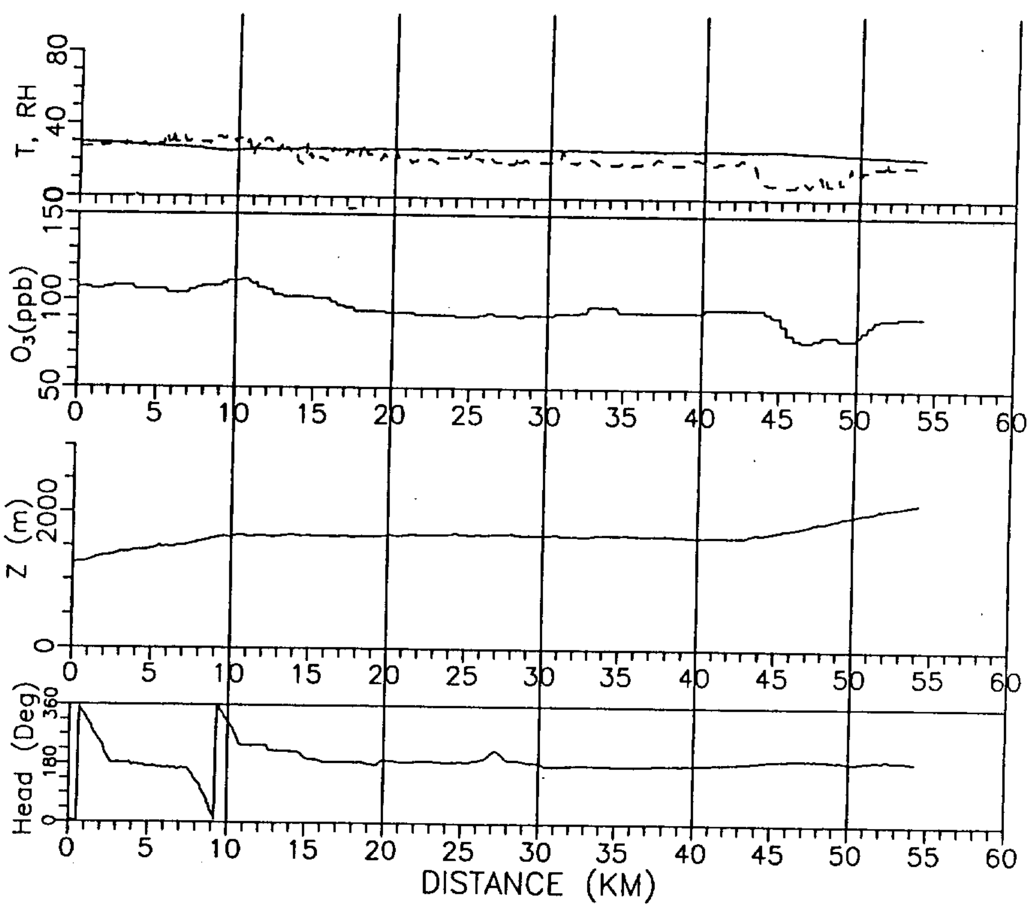
6 c,d. Same as figure 5b but over Auburn (c, 12:59-13:14) and Colfax (d, 13:15-13:36).



6e. Same a 5c but for combined traverse Auburn to Colfax and spiral near Colfax (13:15-13:36).

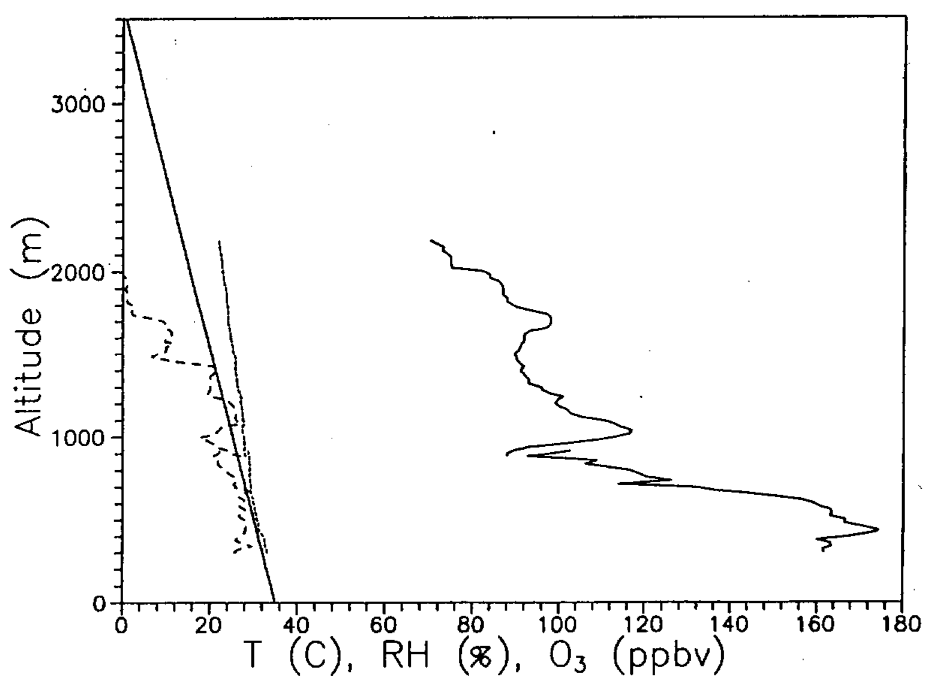


a.



b.

7 a. Same as 5a but for data files 8,9 and 10.
b. Same as 5a but for traverse from Colfax to Folsom (13:37-13:56).



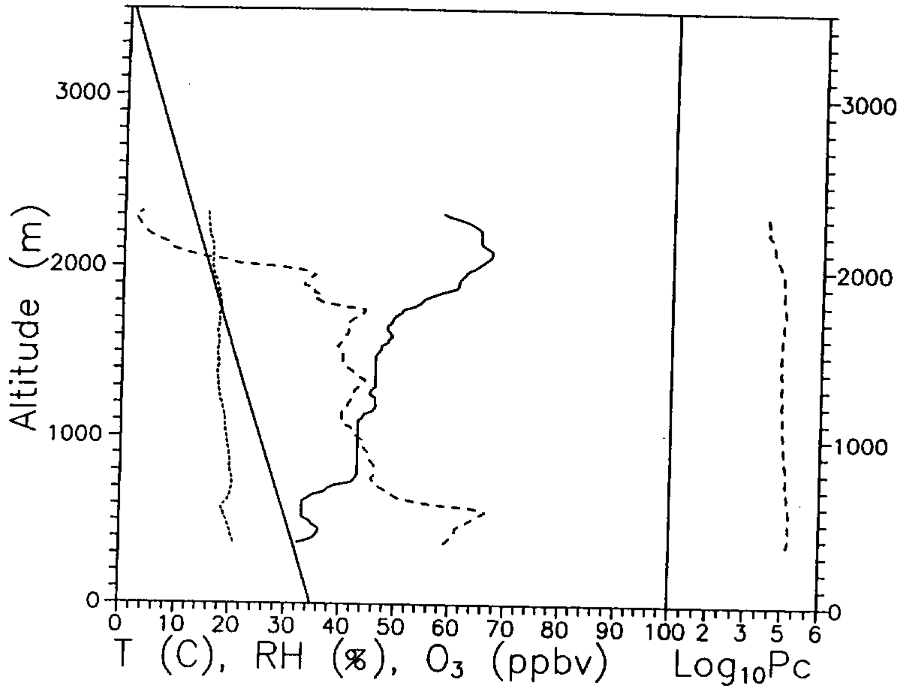
7c. Same as 5b but for data files 9 and first part of 10 (13:58-14:30).

APPENDIX A

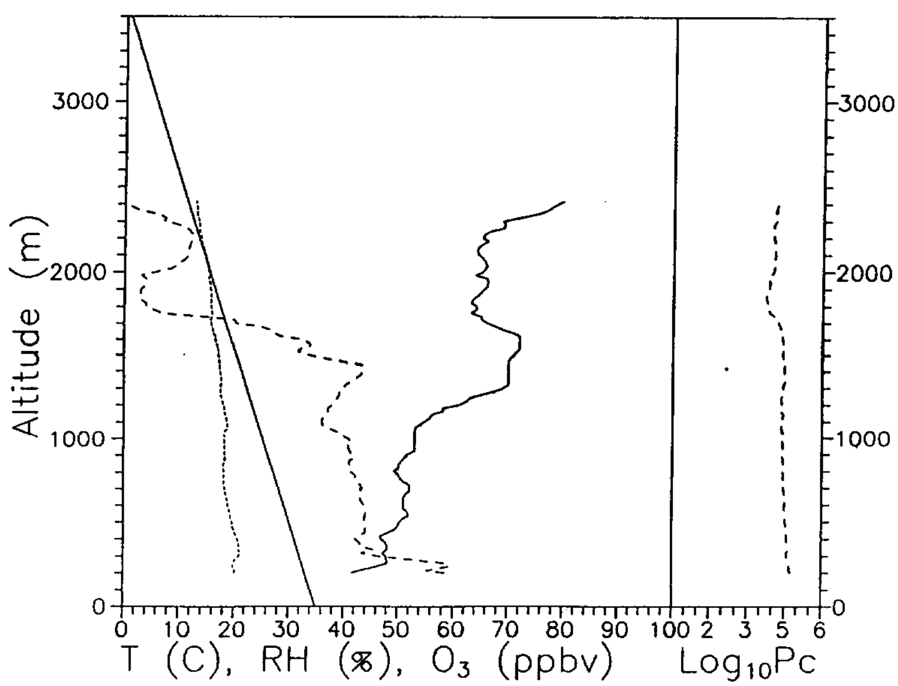
PLOTS OF PROFILE DATA FROM DIAL COMPARISON FLIGHTS.

Profile plots same as for Figure 2b, showing relative humidity (long dashed line), temperature (short dashed line) and ozone concentration, solid line. Solid straight line slanting upward to left represents adiabatic lapse rate. Dashed line to right is the base 10 logarithm of the 0.3 particle count in units of number per m^3.

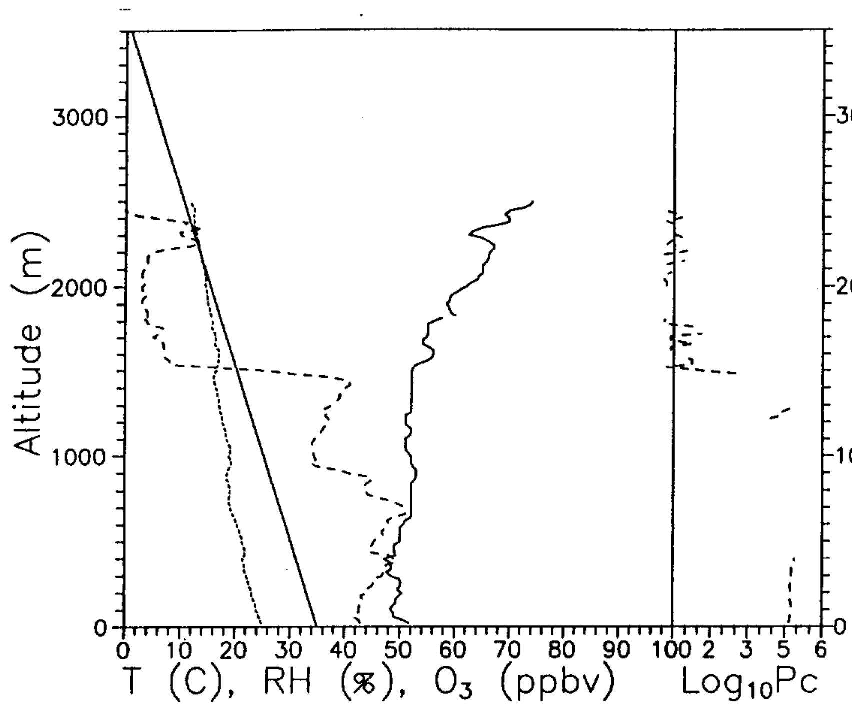
Plots are presented in chronological order.



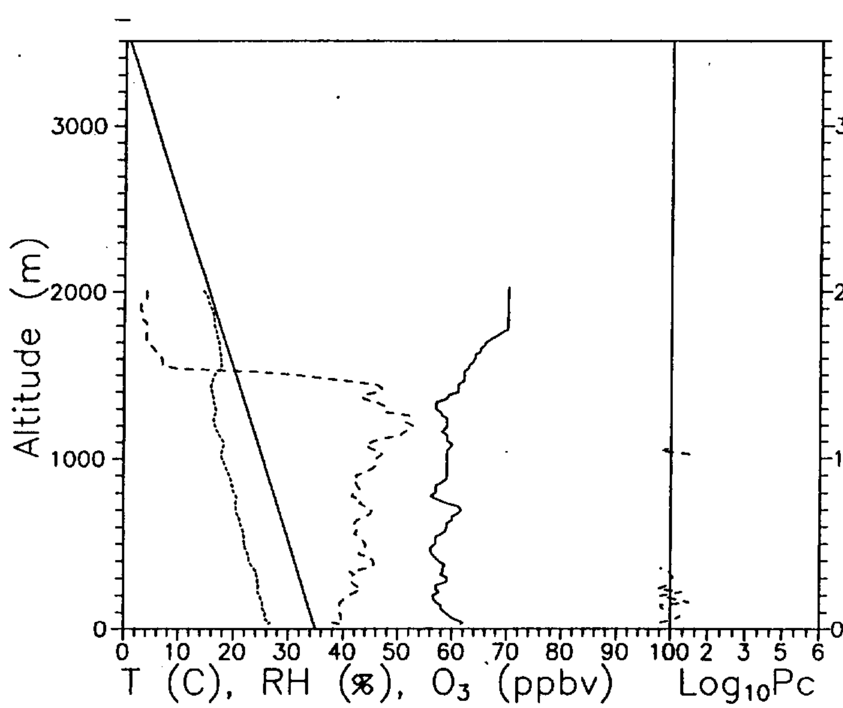
July 14 8:58-9:12



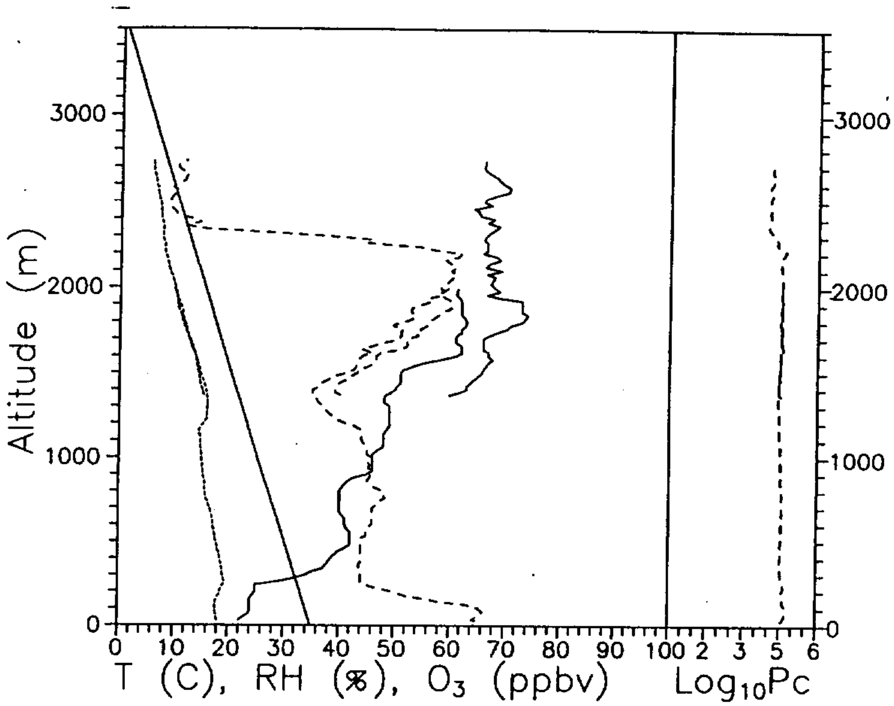
July 14 9:13-9:34



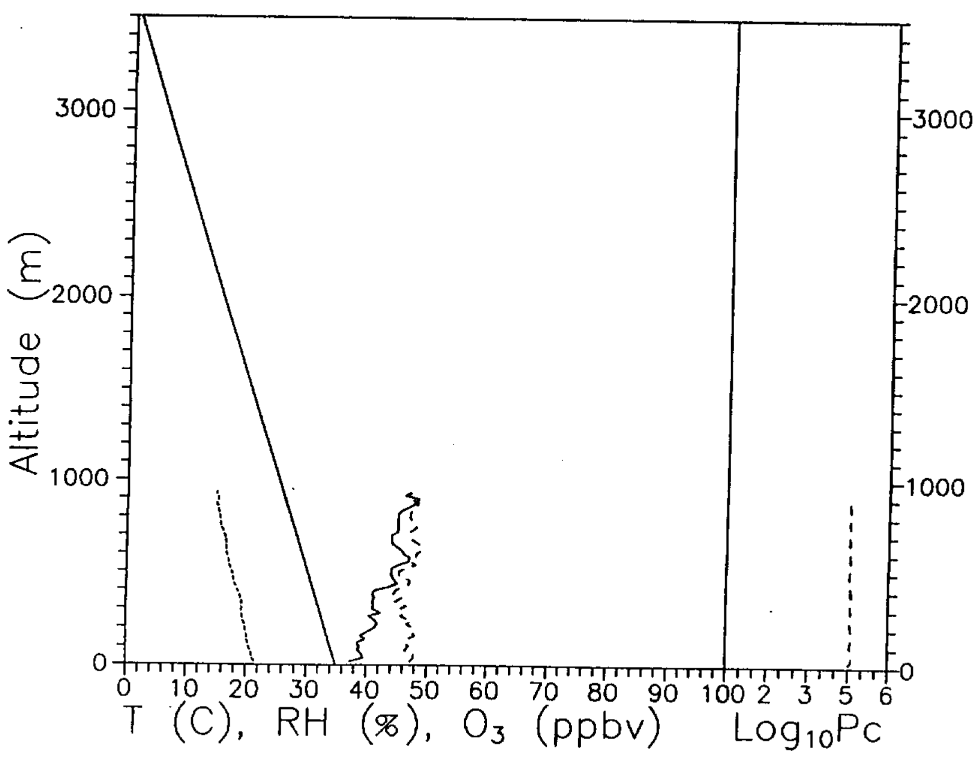
July 14 11:16-11:44



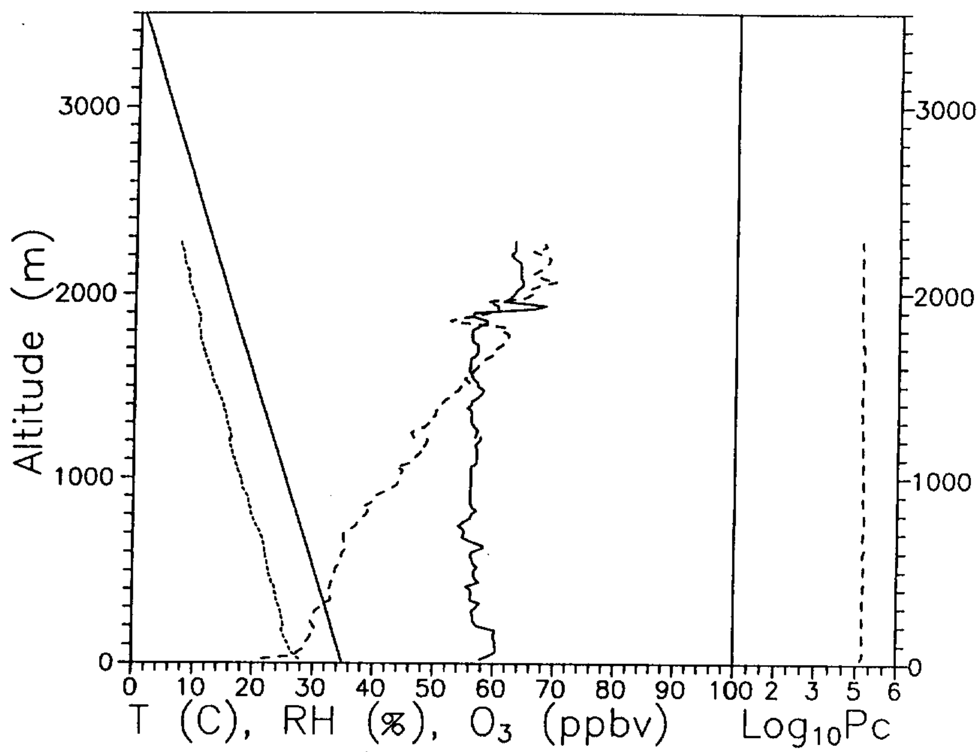
July 14 11:55-12:15



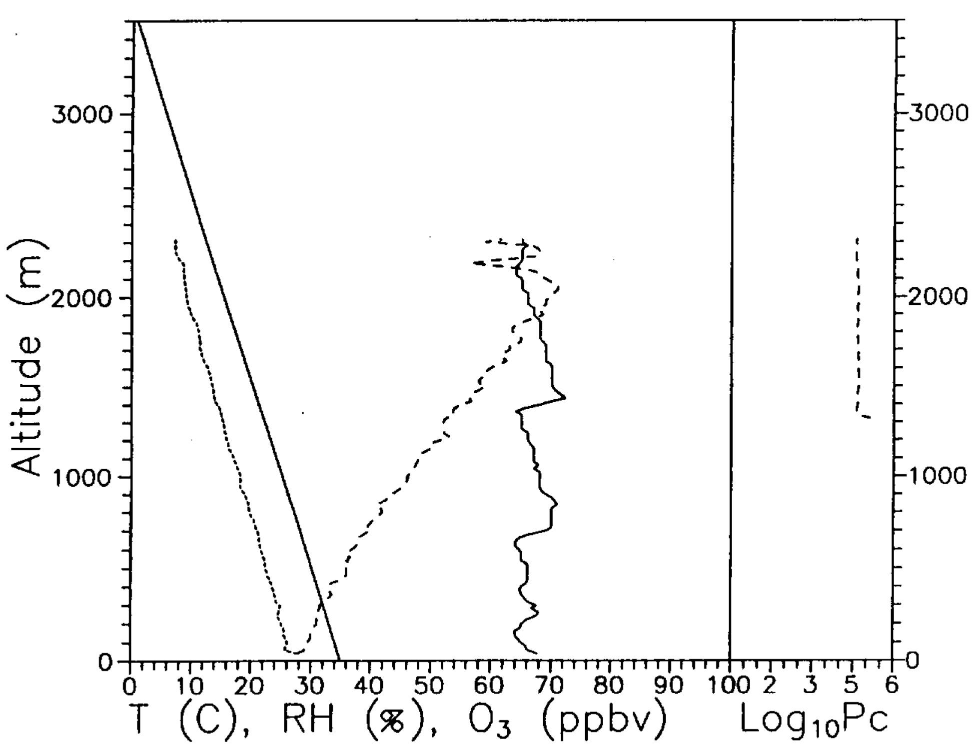
July 15 7:56-8:29



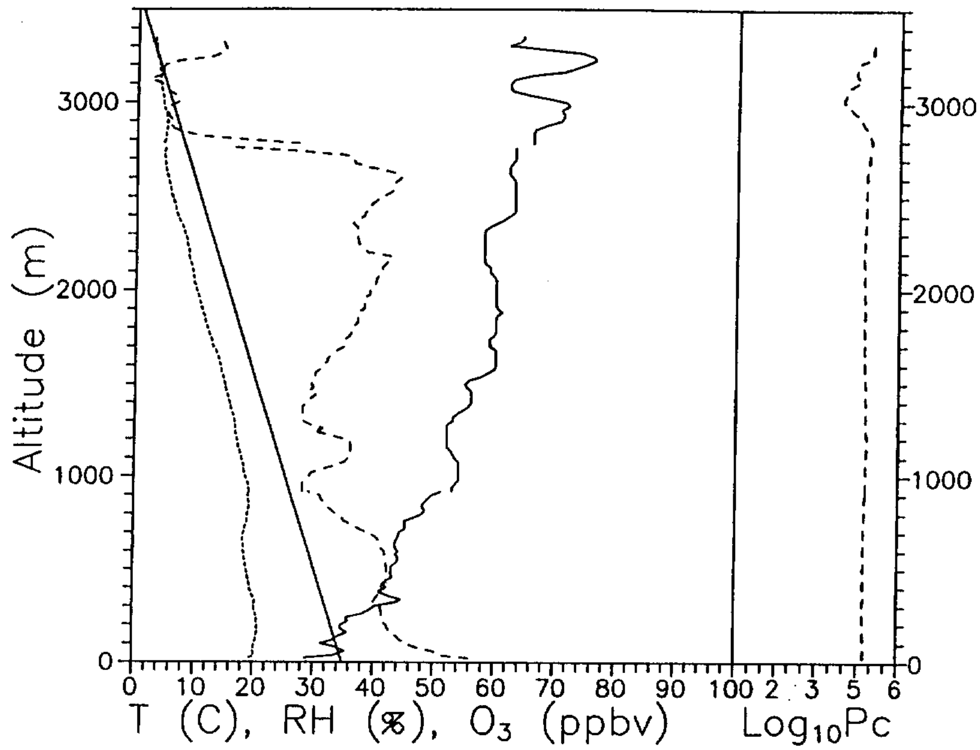
July 15 8:49-9:00



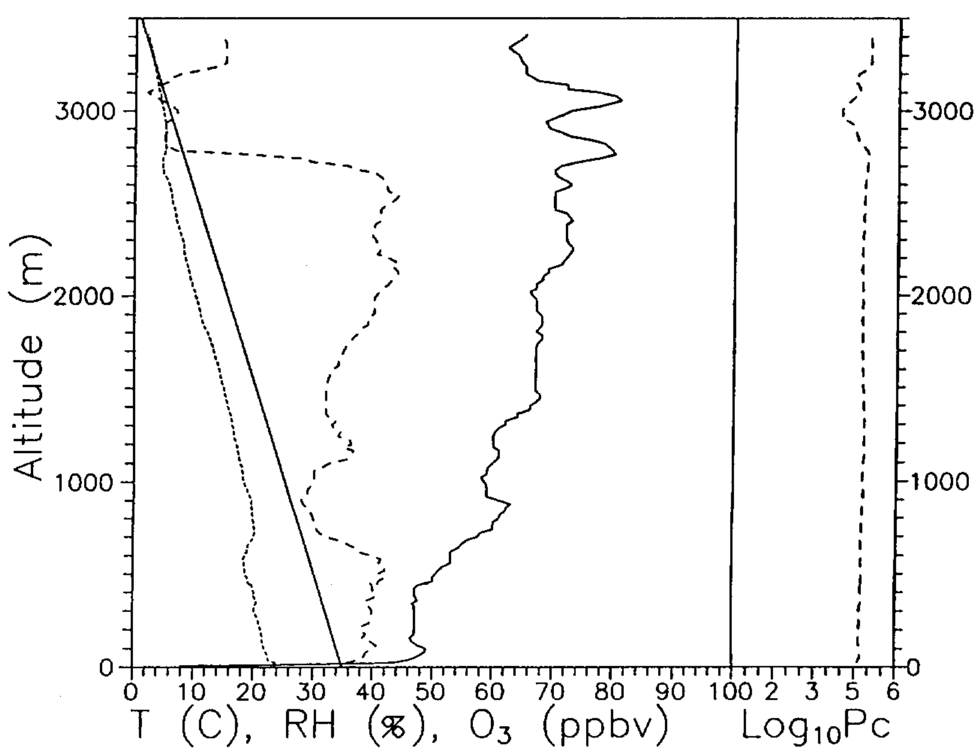
July 15 14:23-14:57



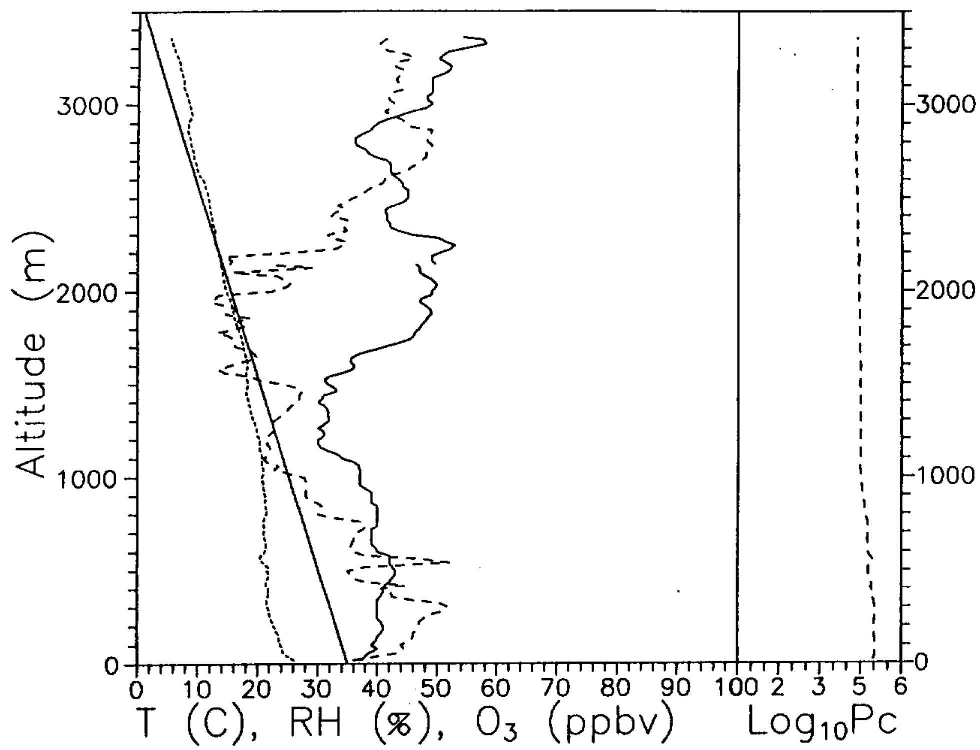
July 15 14:58-15:16



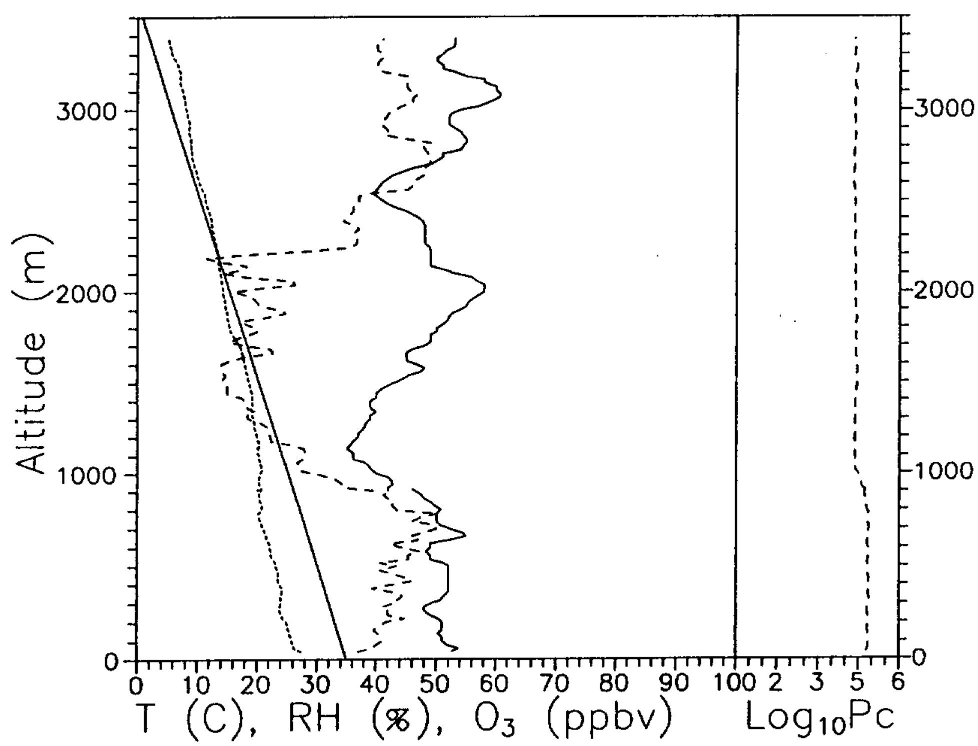
July 16 7:28-8:11



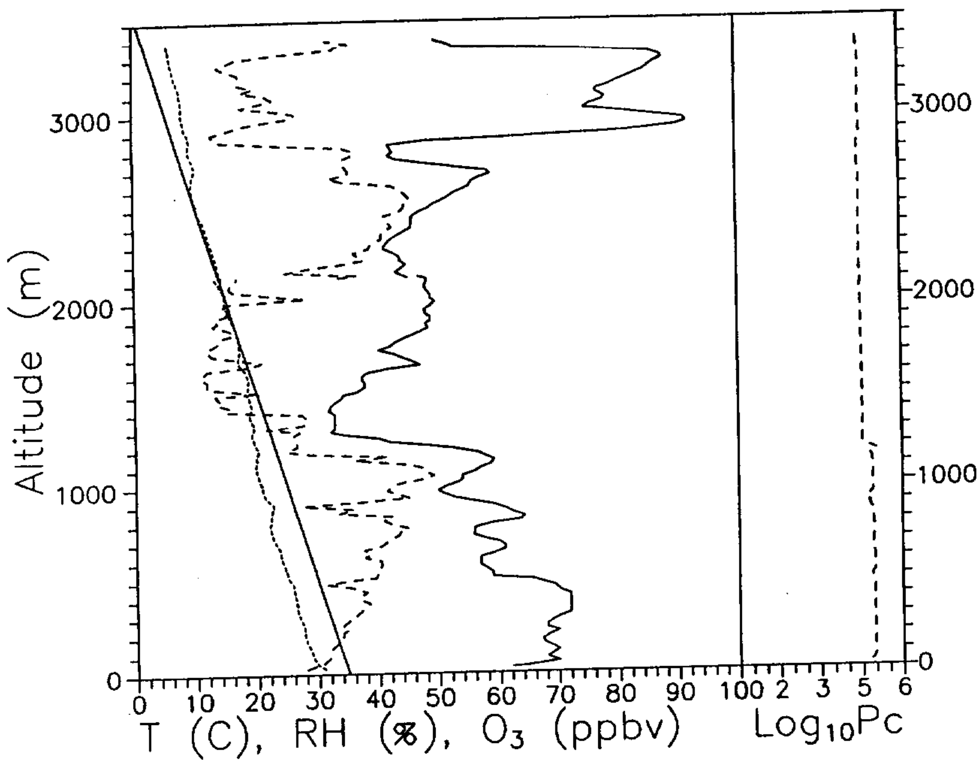
July 16 8:12-8:38



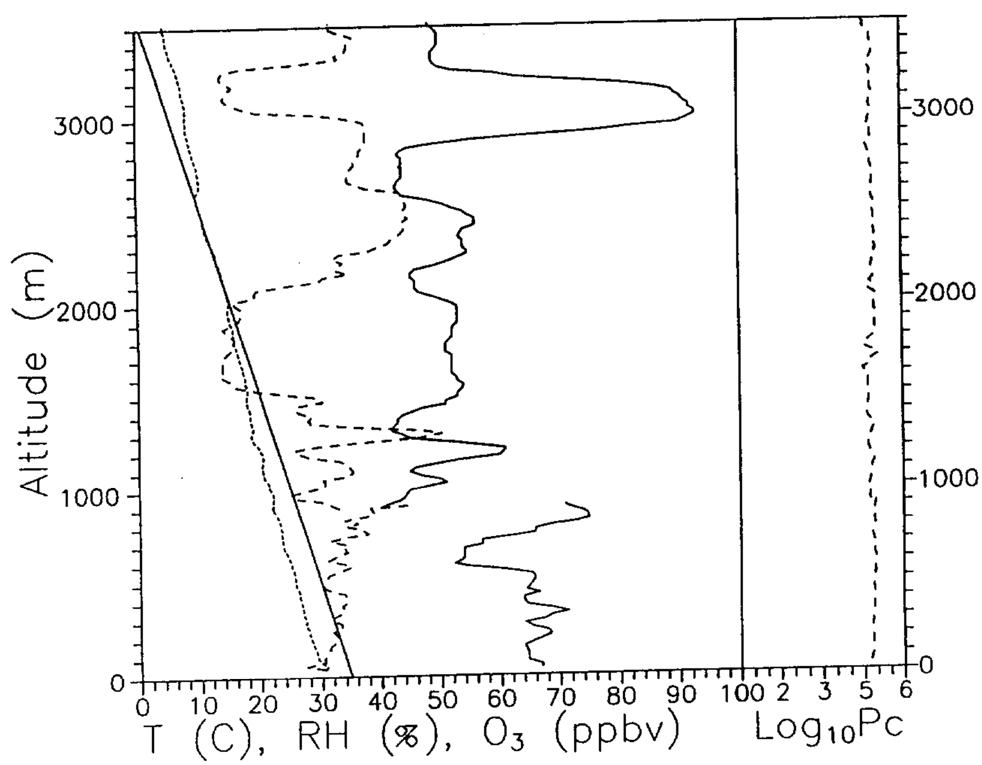
July 19 11:36-12:07



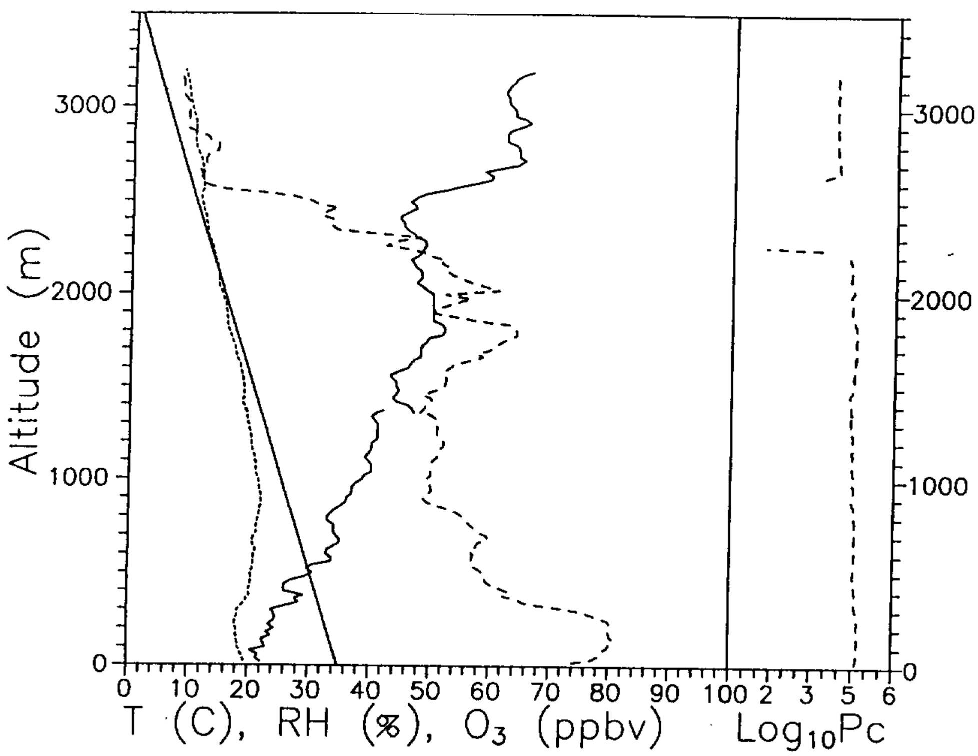
July 19 12:08-12:35



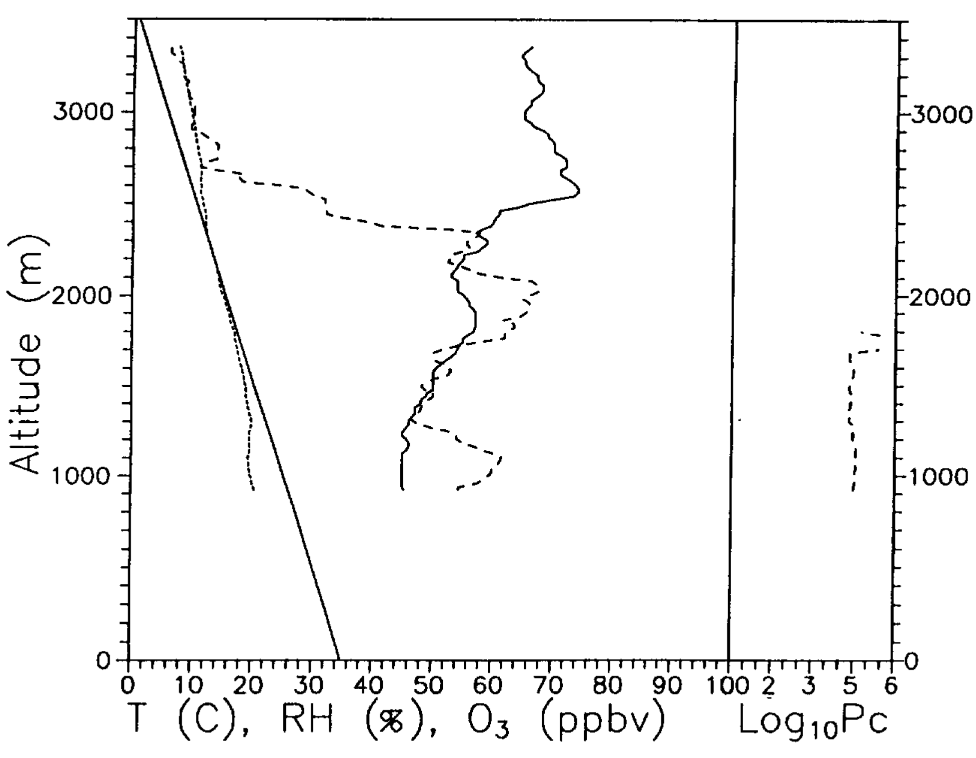
July 19 14:42-15:17



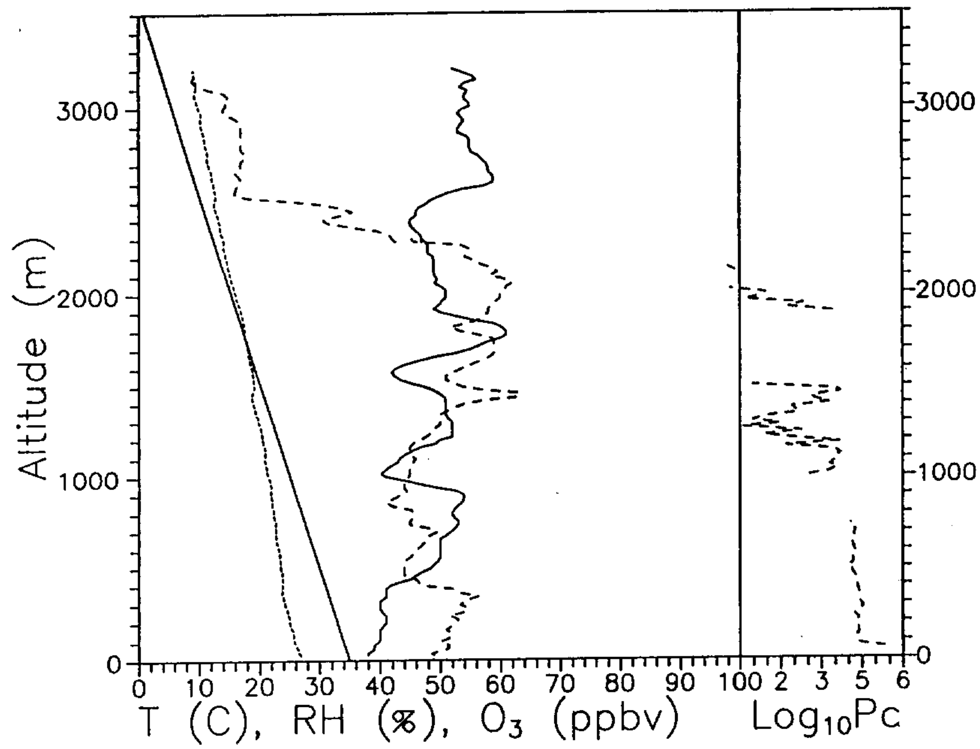
July 19 15:19-15:55



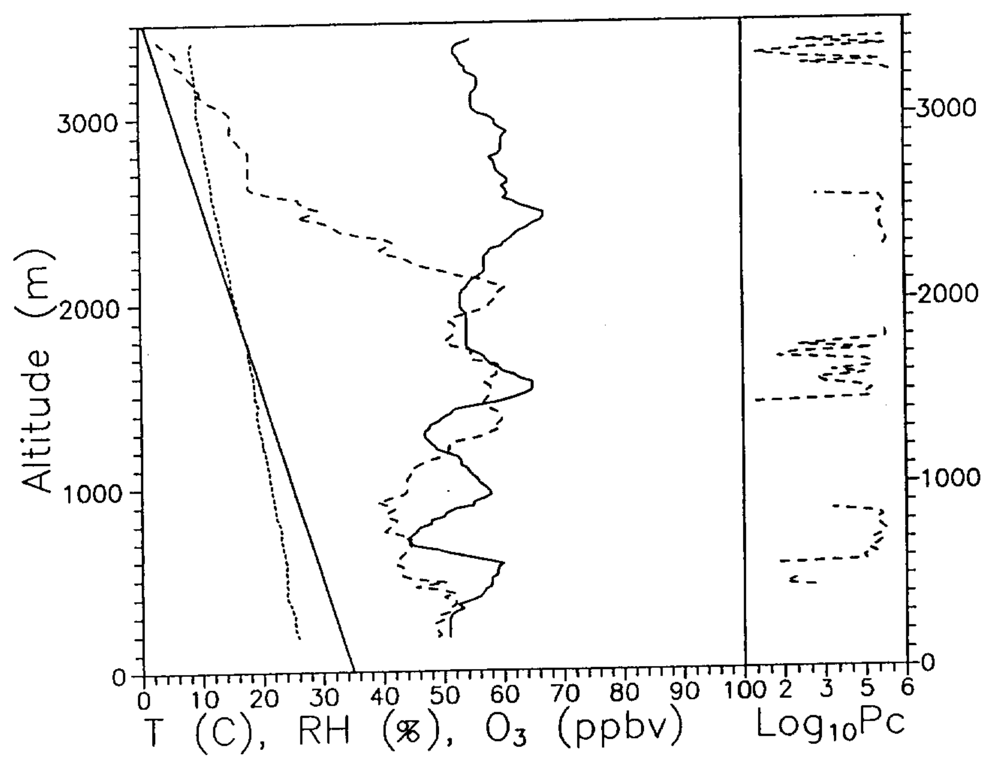
July 20 7:40-8:19



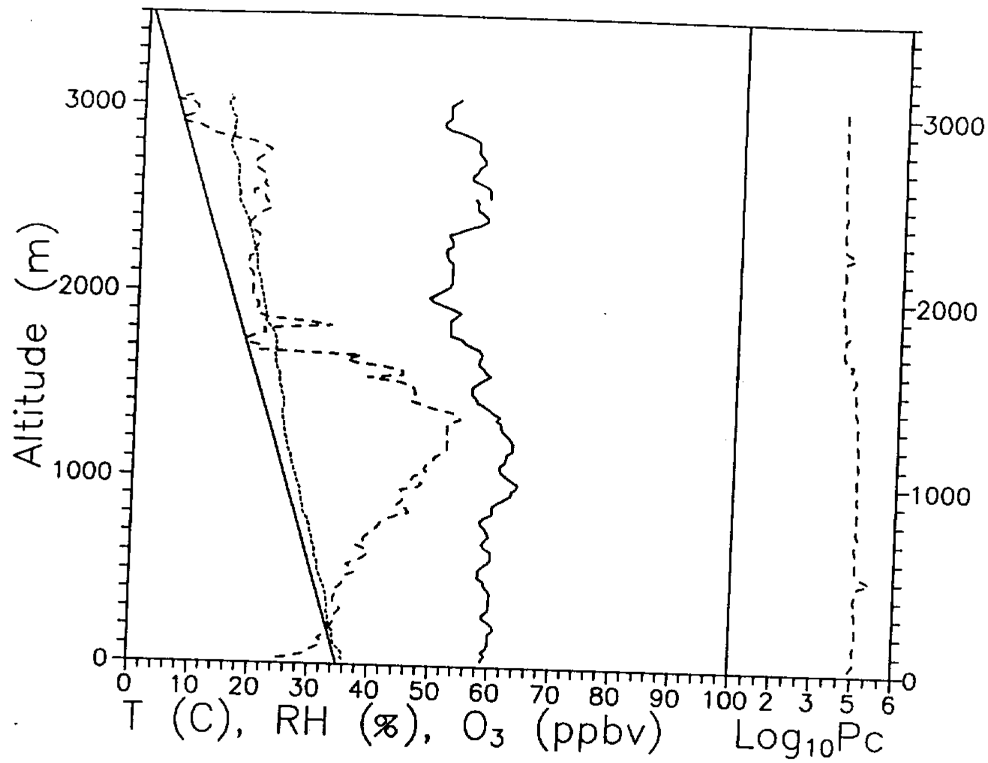
July 20 8:23-8:39



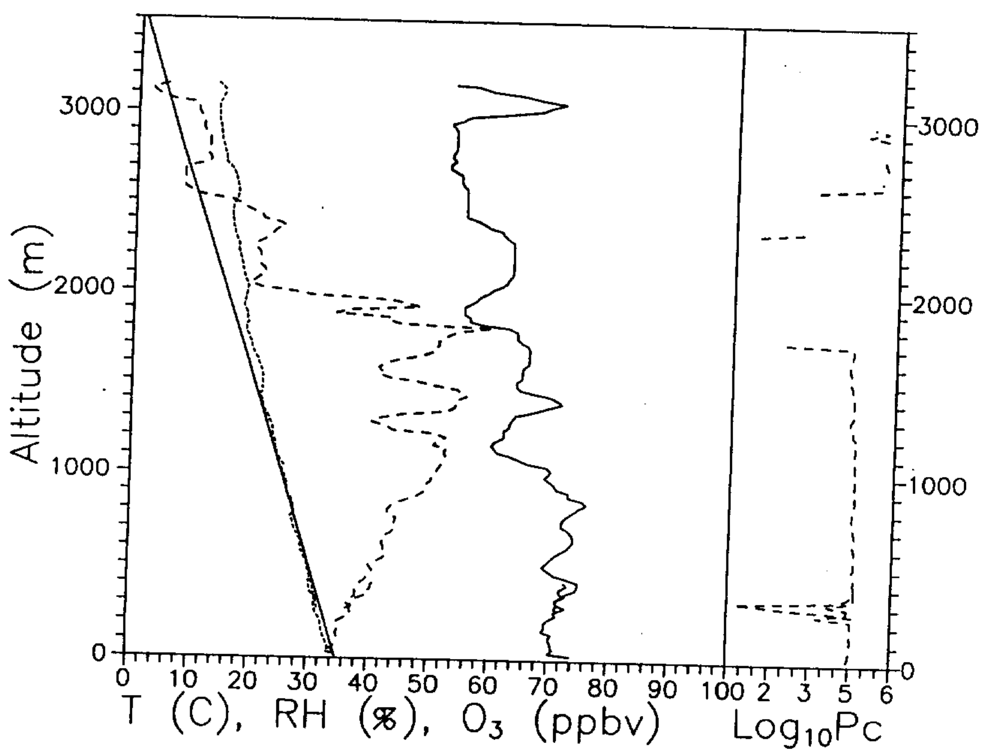
July 20 11:18-11:46



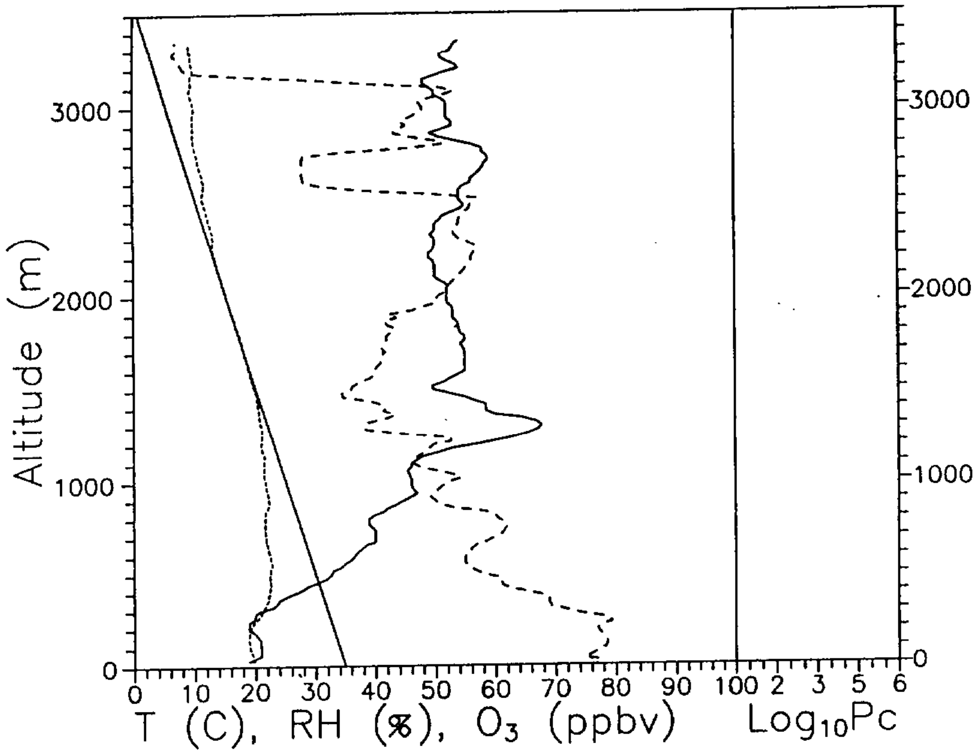
July 20 11:49-12:10



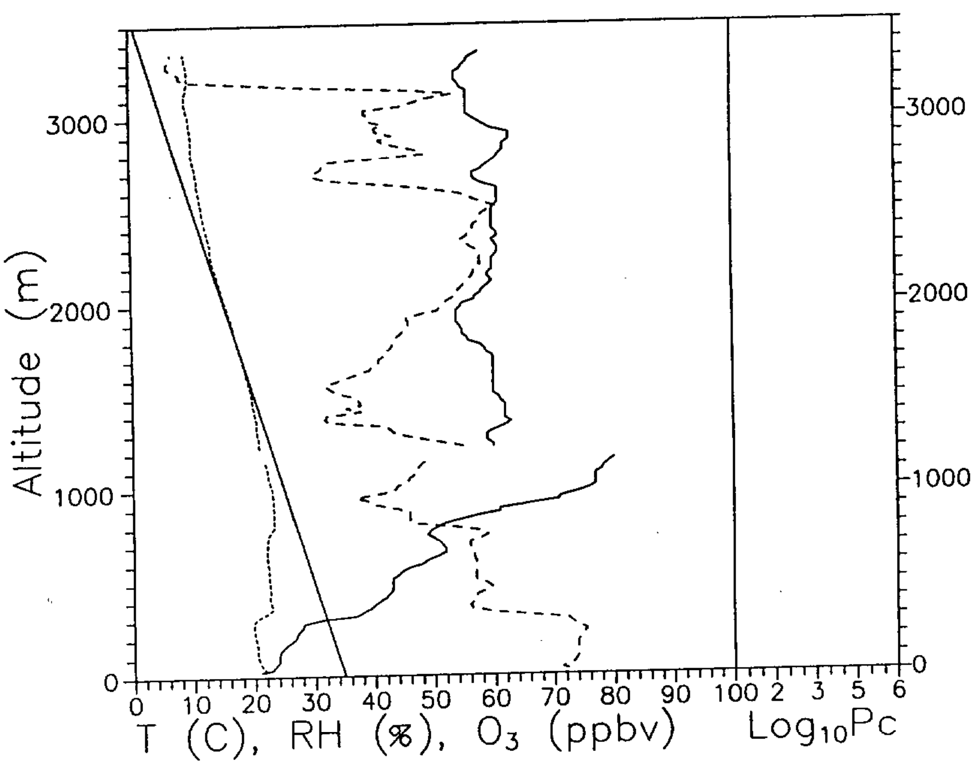
July 20 14:47-15:14



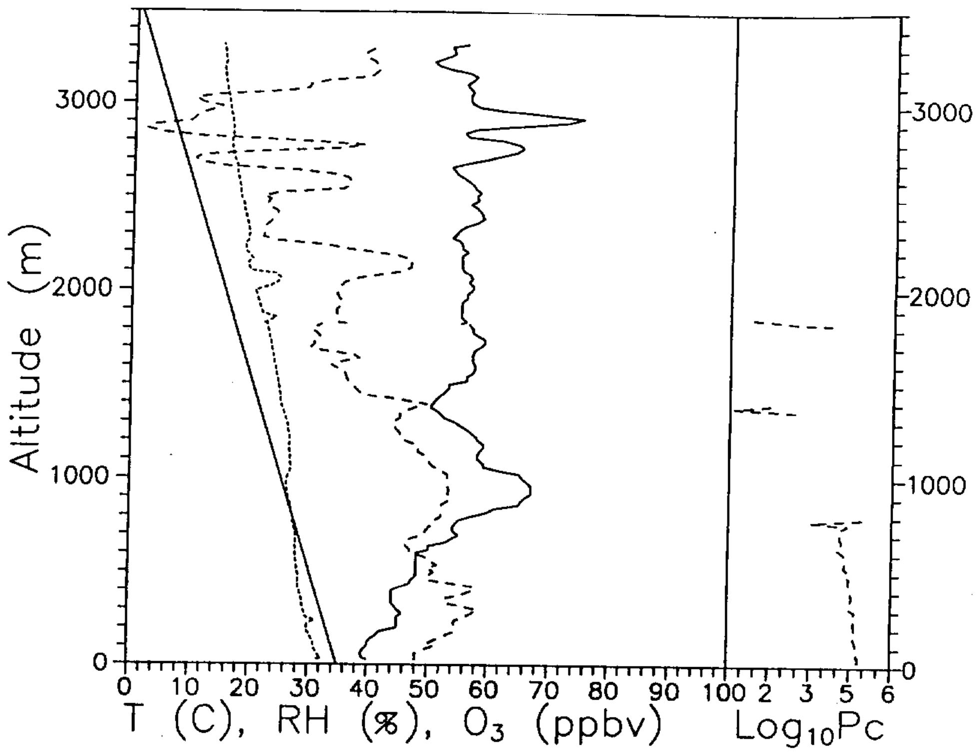
July 20 15:15-15:47



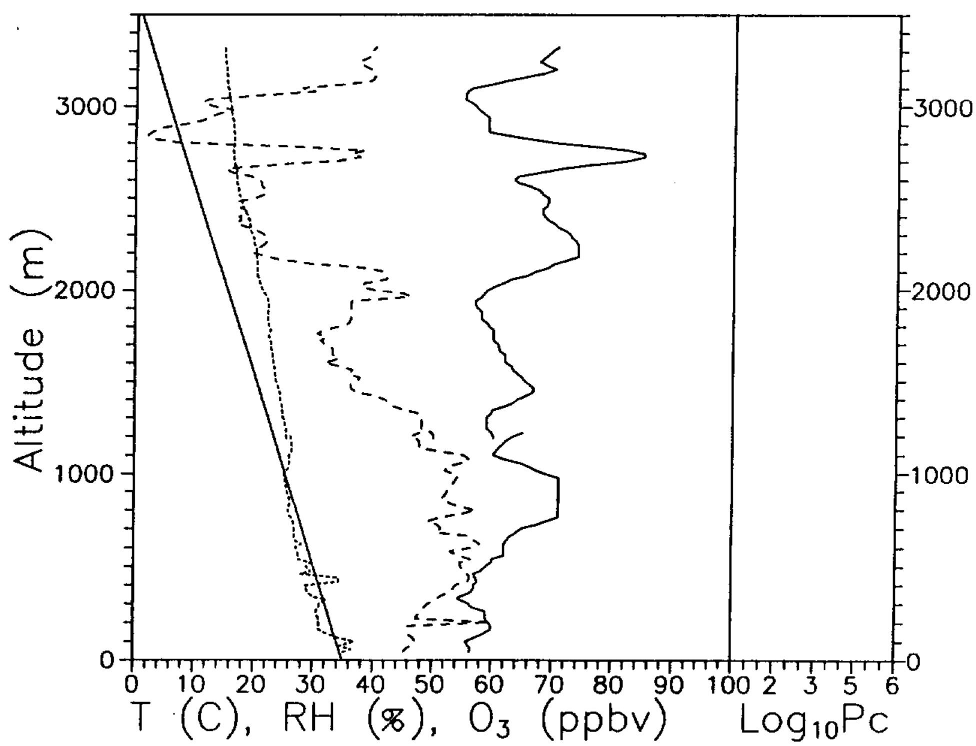
July 21 7:55-8:24



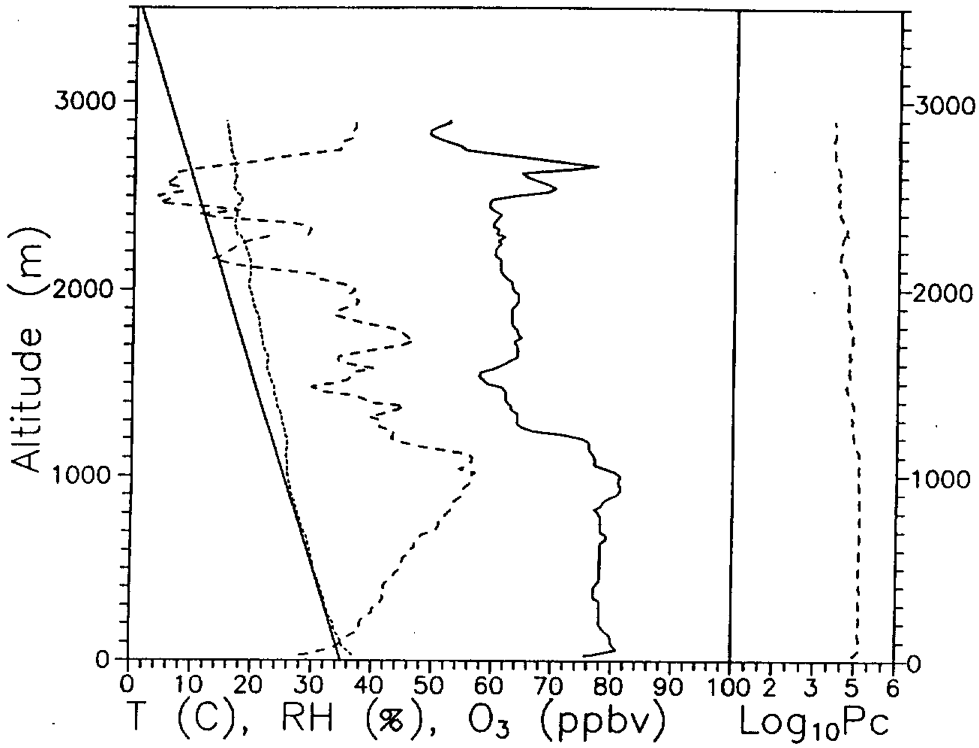
July 21 8:25-8:46



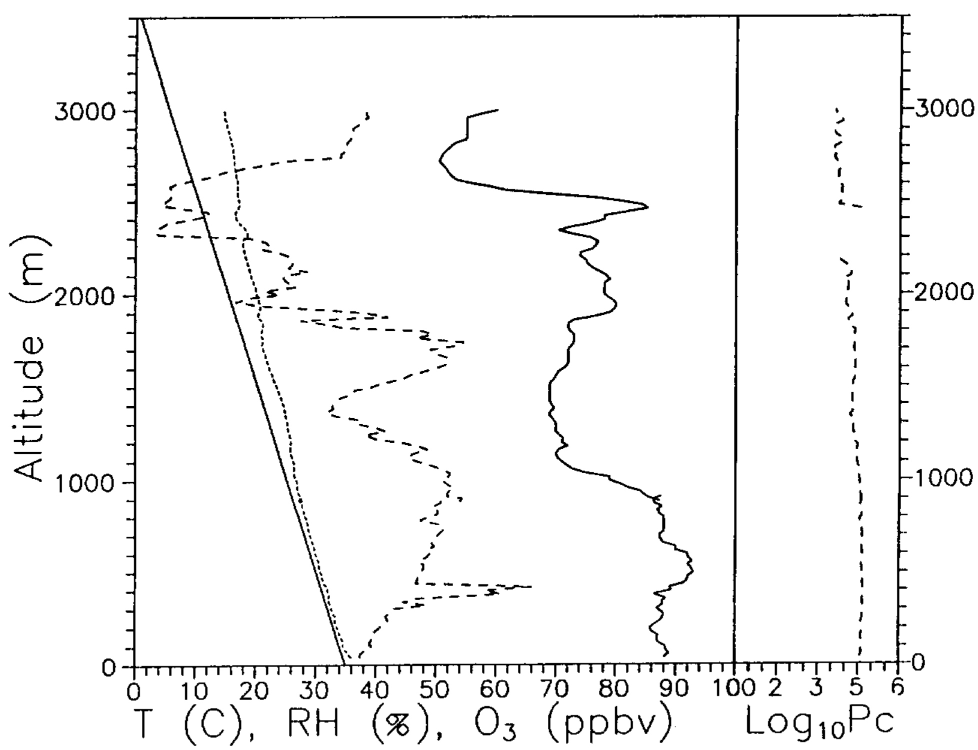
July 21 11:12-11:43



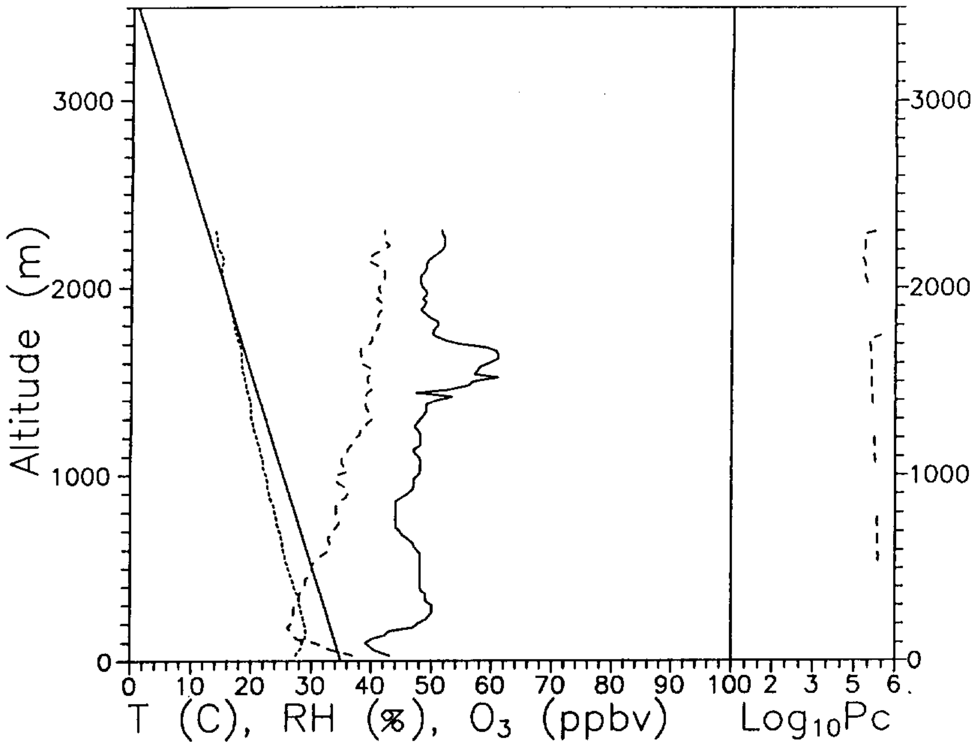
July 21 11:44-12:06



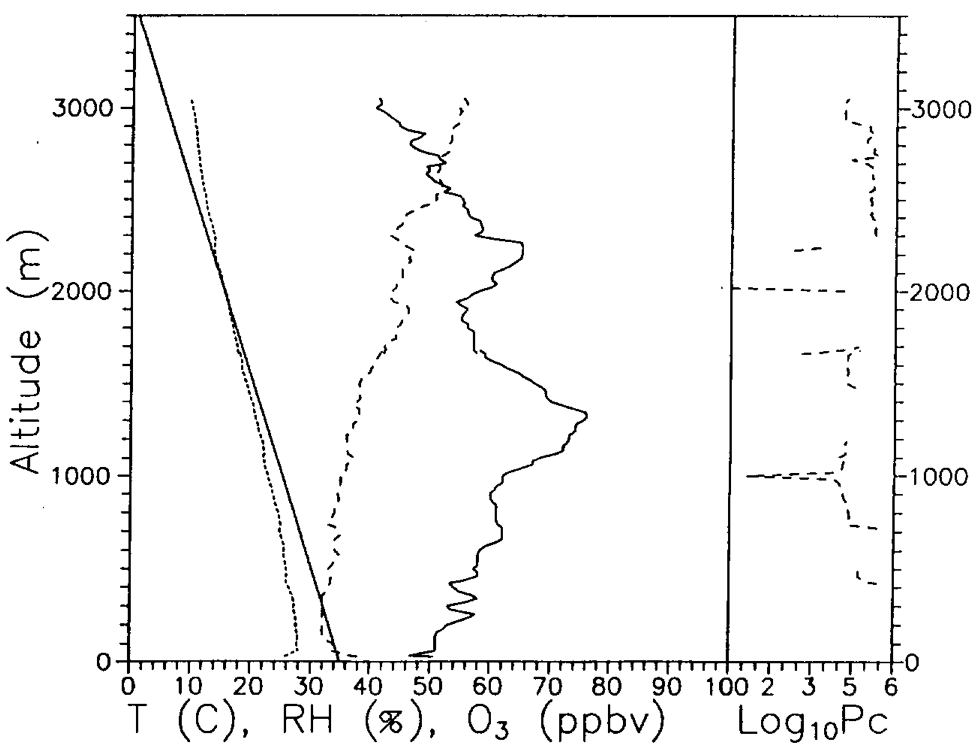
July 21 15:15-15:43



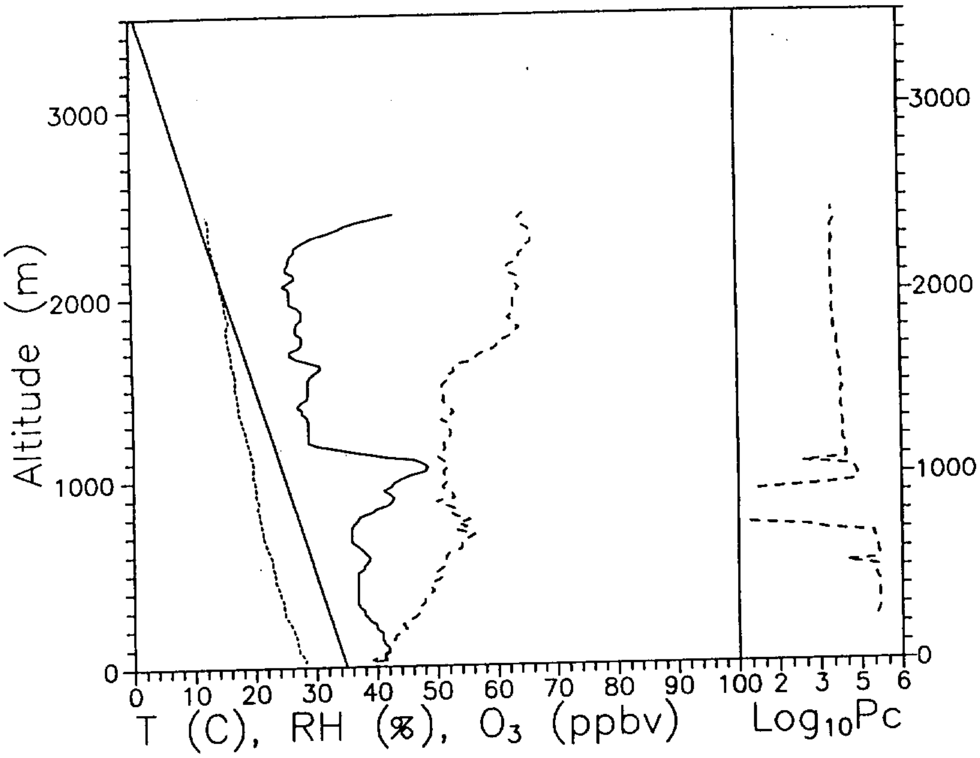
July 21 15:44-16:09



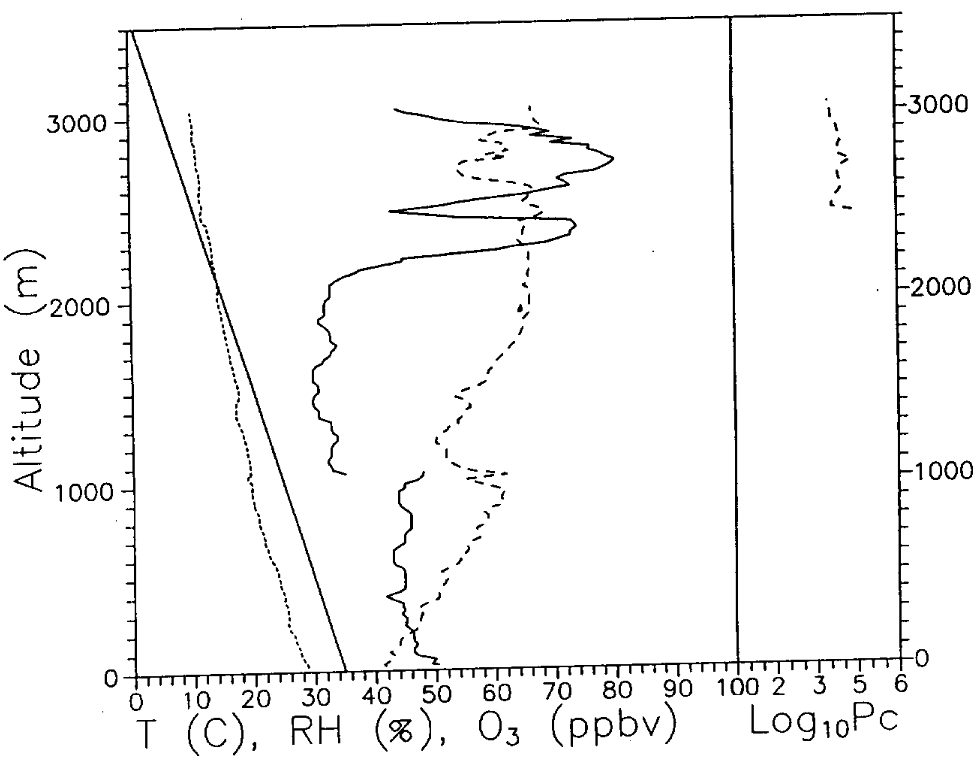
July 21 20:57-21:15



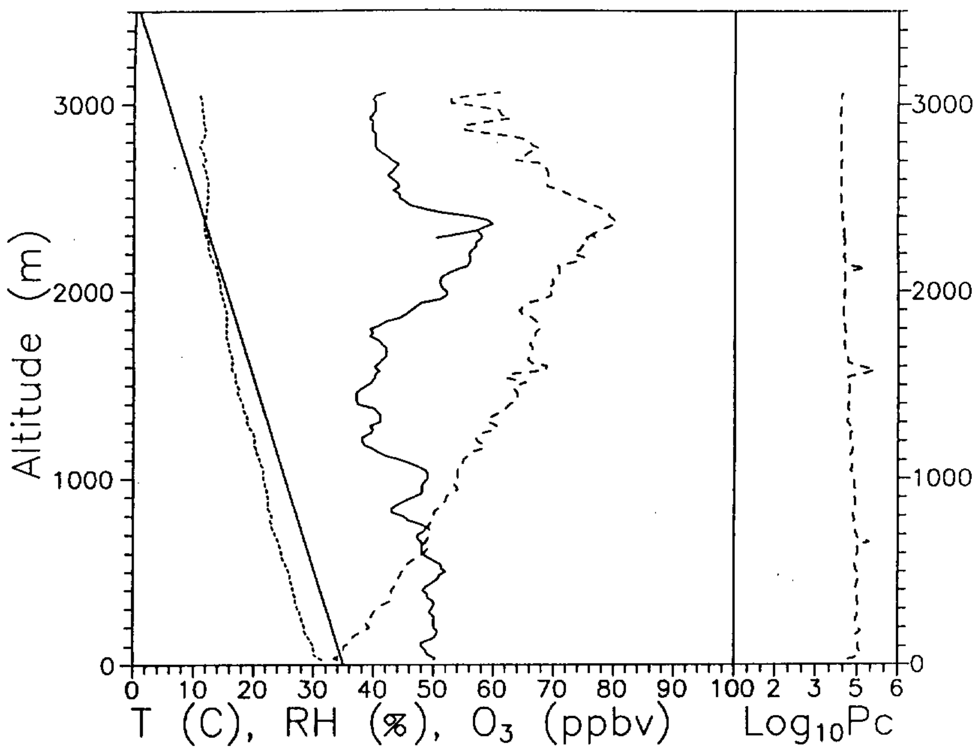
July 21 21:18-21:54



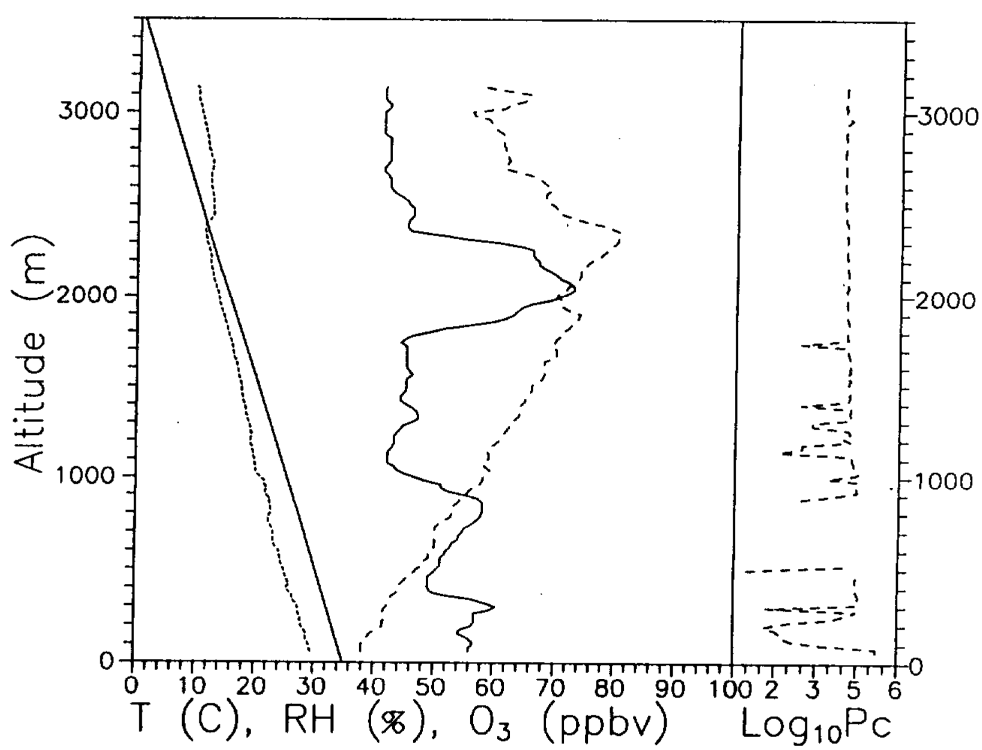
July 22 10:29-10:48



July 22 10:50-11:20



July 22 13:33-14:01



July 22 14:03-14:23